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A

COMPENDIUM

OF

NATURAL PHILOSOPHY,

ADAPTED TO THE USE OF

SCHOOLS AND ACADEMIES.

BY DENISON OLMSTED, LL. D.,

PROFESSOR OF NATURAL PHILOSOPHY AND ASTRONOMY IN YALE COLLEGE.

REVISED BY

E. S. SNELL, LL. D.,

PROFESSOR OF MATHEMATICS AND NATURAL PHILOSOPHY IN AMHERST COLLEGE.

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PREFACE.

NOTWITHSTANDING the recent multiplication of works on Natural Philosophy, intended for those pupils who are found in the more advanced classes of our Academies and High Schools, yet the "Compendium" of Professor Olmsted has continued in use somewhat extensively to the present time. Of late, however the demand has been frequently made for another and more thorough revision. In attempting such a revision, while I have adhered to the general plan of the author, I have endeavored to discuss all the subjects with more conciseness, keeping in view the fact, that the work is used chiefly for *recitation.* And, as it is designed for a class of learners entirely distinct from those for whom the College edition was prepared, I have avoided almost entirely the transfer of paragraphs, or even sentences from that work to this. In a few instances the arrangement of topics is changed, to secure a more natural connection between them. In Hydraulics, Acoustics, and Optics, I have endeavored to convey definite ideas of the nature of *wave-motion,* as it exists in water, air, and the luminiferous ether; and in Optics, have introduced a brief account of those interesting properties of light, which are of recent discovery, and to which there is only an allusion in preceding editions.

It is hoped that the changes thus made will meet the wishes of those who have desired a revision, and that the more condensed statements and descriptions will be found to adapt the work better than before to the purposes of the class-room.

E. S. SNELL.

AMHERST COLLEGE, *September*, 1863.

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COMPENDIUM

OF

NATURAL PHILOSOPHY.

INTRODUCTION.—GENERAL PROPERTIES OF MATTER.

1. *Definitions.—Natural Philosophy*, or *Physics*, is the name of the science which treats of the *general laws of matter*. The word *law*, in this definition, signifies *the uniform mode in which the forces of nature act*. Thus, it is a law of falling bodies, that the *distances* vary as the *squares of the times;* and in optics it is the law of the reflection of light, that *the angle of incidence equals the angle of reflection*. The falling of bodies, and the reflection of light, always take place in accordance with these statements; hence they are called *laws*.

A *body* is any portion of matter of whatever kind. If the body is exceedingly small, it is called a *particle*.

The *general laws* considered in Natural Philosophy, relate to *bodies* or *particles* of matter, without regard to the particular *kind* of matter of which they consist. The minutest portions,

---

Define *Natural Philosophy*. What does the word *law* signify? Give examples. Define *body*, and *particle*. To what do the general laws of philosophy relate?

into which matter can in any way be divided, are called *atoms*; and these possess various properties, and according to their kind act in different modes on each other. The *specific laws*, governing the mutual action of atoms, belong to the science of Chemistry, and not to Natural Philosophy.

2. *Force* is any cause which tends to *move* a body, or to *change* its motion. Thus, *gravity* is a force, tending to move bodies toward the centre of the earth. The *momentum* of water, the *elasticity* of steam, and the *strength* of animals, are also forces, which are constantly in operation, producing and changing the motions of bodies.

A force is called *impulsive*, if it has no sensible continuance; if it continues to act for a time, it is called *accelerative.*

Mass signifies the quantity of matter in a body; *volume*, the space which it occupies; and *density*, the quantity as compared with the space. The unoccupied parts within the volume of a body are called *pores.*

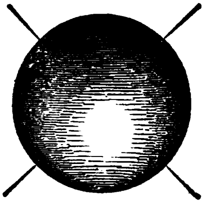
3. *Extension and impenetrability.*—These are two properties of matter, which are not only universal, but *essential* to its very existence. A particle of matter, however small, fills some space—has some length, breadth, and thickness; or, in other words, has *extension.* It also *excludes every other particle from that space*, so long as it occupies it; that is, it is *impenetrable.* When a nail is driven into wood, the particles of wood are *displaced* by the nail, and no two particles occupy the same place at once. So water, when it soaks into wood, only fills the pores, or vacant spaces between its particles.

4. *Gravity.*—This property is universal, and signifies that

What are *atoms?* What science discusses the relations of atoms? Define *force.* Give examples of force. When is a force called *impulsive?* When *accelerative?* Define *mass*, *volume*, *density.* What are the essential properties of matter? Why so called? Define *gravity.*

tendency which all matter has toward all other matter. In Mechanics, it is usually limited to *the tendency of all bodies toward the center of the earth;* for between the bodies themselves, this force is so slight, that it is difficult to detect it. We observe this tendency in the *motion* of falling bodies, when they are not supported, and in the *pressure* or *strain* which they produce on that by which they are upheld. The pressure thus exerted is called the *weight* of the body. Since the earth is nearly spherical, bodies on different sides of it, in falling toward its center, move in all possible directions, as represented in Fig. 1. As all particles alike have this tendency to the earth, therefore, the more matter, the more weight; that is, *gravity*, or *weight*, *varies as the quantity of matter.*

Fig. 1.



5. *Inertia.*—This term denotes the tendency in matter *to preserve its present condition of motion or rest.* If a body is placed at rest, it never moves, till a force puts it in motion; and it is equally true, that if a body is moving, it can never stop itself, or alter its motion in the slightest degree. Whenever a body loses any motion, or changes its direction, it is because some force acts upon it. Inertia, as well as gravity, varies as the quantity of matter.

6. *Other general properties.*—In addition to the foregoing universal properties, which belong equally to all matter, there are many other general properties, some of which differ greatly in different substances; such as *cohesion*, *compressibility*, and *elasticity.*

7. *Cohesion* is the force which binds particles together to

What is *weight?* How does it vary? State the meaning of *inertia.* Illustrate inertia. Name properties of matter, not universal. What is *cohesion?*

form a body. It exists in various degrees; it is feeble in a lump of earth, strong in a hempen cord, and very strong in an iron wire. The strength of cohesion is measured by observing the number of pounds which are required to pull asunder a rod of given size. For example, a bar of steel, one-tenth of an inch square, is pulled apart by a weight of 1,500 lbs.; a rod of lead, of the same size, by 9 lbs.

The great cohesion of iron is seen in suspension bridges (Fig. 2), by which immense loads, in addition to the weight of the bridge itself, are supported by ropes made of iron wire.

Fig. 2.

8. *Compressibility* is, in a greater or less degree, a property of all masses of matter. Air is very compressible, and may easily be reduced to one-half or one-fourth of its volume; while water is so slightly compressible, that for many years it was regarded as absolutely incompressible. The fact that all bodies are compressible, proves them to be porous.

9. *Elasticity* is the power of a body to restore itself to its original form and size, after the compressing force is removed. Those bodies in which the restoring force is equal to the compressing force, are called *perfectly elastic.* Air and all gases are of this class; water, glass, and tempered steel, though they yield

---

Is its strength the same in all bodies? Illustrate. How is cohesion measured? Example of great cohesion. Define *compressibility* and *elasticity.* Examples of *perfect* elasticity.

but little to compressing forces, are almost perfectly elastic. On the other hand, lead, and soft clay, are examples of bodies nearly destitute of elasticity. Elasticity is called *torsion*, when it tends to untwist a thread or wire which has been twisted.

10. *Divisibility.*—Matter can be divided beyond any known limit. Many examples might be named, in which matter is divided into portions inconceivably small. In gold lace, the thread is covered with a film of gold so thin, that a foot of the thread contains only one-6,000th of a grain of gold. An inch, therefore, would contain but one-72,000th of a grain; and since the 500th of an inch can be seen by a microscope, so small a quantity of gold as one-36,000,000th of a grain is distinctly visible. Yet there is reason to think that the ultimate atoms of gold are vastly smaller still.

A grain of musk is capable of filling a large room with its odoriferous particles for several years, without any sensible loss of weight. The thread by which a spider lets himself down, although nearly invisible on account of its fineness, is said by naturalists to consist of more than 6,000 single threads, each visible through the microscope. Yet there doubtless is a limit to the divisibility of matter, though unknown to us; for there is strong reason to believe that there are certain unalterable parts, called *ătoms*, beyond which no power but that of the Creator can ever carry the division.

11. *Indestructibility.*—In all the changes which matter undergoes, there is not a particle lost or destroyed. When water is boiled away, it passes into the invisible form of vapor, which, on being cooled, returns again to the state of water, without the slightest loss. When wood is burned, it is not *destroyed*, but

---

What is *torsion?* Is there a limit to *divisibility?* Examples in *gold lace*, *odor* of musk, *spider's web*. Is *water* destroyed when boiled away? *Wood*, when it is burned?

only *changed* into various other forms, called *the products of combustion;* these are, ashes, watery vapor, and various kinds of gas. If they are all carefully collected and weighed, their united weights equal the weight of wood, before it was burned. These products of combustion, in the economy of nature, are employed in the construction of other bodies in the vegetable and animal world. Man has no more power to *destroy* a particle of matter, than he has to *create* it.

12. Natural Philosophy is usually divided into the following branches: *Mechanics, Hydrostatics, Pneumatics, Acoustics, Electricity, Magnetism,* and *Optics.*

The first three are to be regarded as the subdivisions of a general branch, called *Mechanics.* Such a subdivision is required, because there are three forms of matter, *solid, liquid,* and *gaseous.* Hence, the mechanics of solids is called Mechanics; the mechanics of liquids, Hydrostatics; the mechanics of gases, Pneumatics.

How is it shown that burning a substance does not destroy it? What are the *branches* of natural philosophy? What is said of the first three? Why are there three branches of mechanics?

PART I.—MECHANICS.

CHAPTER I.

MOTION AND FORCE.

13. *Mechanics* is that branch of Natural Philosophy, which treats of *the equilibrium and motion of bodies.* A body is said to be in equilibrium, when two or more forces act upon it in such a way as to prevent its motion.

14. *Absolute and relative motion.*—Motion is change of place, and is distinguished into absolute and relative. *Absolute* motion is a change with respect to space itself. *Relative* motion is a change with respect to surrounding objects. When a person walks abroad, he is in motion relatively to the earth's surface, and the objects upon it; and it is by these that he judges of his motion. If he is walking on the deck of a ship, he estimates his motion by the parts of the vessel; this is *one* relative motion; but if he can look on shore, and notice objects there, he perceives that he has *another* motion in relation to *them.* If he observes the stars, he becomes aware of a *third* motion relatively to those bodies, as he is carried eastward by the earth's rotation on its axis. Again, in studying astronomy, he learns that he has a different motion still *in respect to the sun,* since he accompanies the earth around it every year. Moreover, it is unquestionably true, that the whole solar system is moving, so

---

Define *mechanics.* What is *motion?* What is *relative* motion? Illustrate by walking on the earth, and on board of a ship. Motion in relation to the heavenly bodies.

that we all have on that account a relative motion different from all the foregoing, *in respect to other systems of worlds.* Though we *conceive* of such a thing as absolute motion, it is utterly impossible for us to know what it is, because all space is alike to us, and we have no power of estimating motion except by observing other bodies. Therefore, the words *motion* and *rest*, have in natural philosophy, as they have in common life, only a *relative*, and not at all an *absolute* signification.

15. *Motions classified.*—When a body moves over equal spaces in equal times, it is said to have a *uniform* motion. If the spaces become greater and greater each second, the motion is *accelerated;* if less and less continually, it is *retarded.* And, if a body gains an equal amount of motion every second, it is *uniformly accelerated;* if it loses an equal amount every second, it is *uniformly retarded.*

Velocity is the space passed over in a second, and is usually expressed in feet.

16. *Uniform motion.*—Since a body, when moving *uniformly*, passes over an equal space every second, the space described in one second, multiplied by the number of seconds, equals the whole space described. Hence,

1. The *space* equals the *velocity* multiplied by the *time;* or, using the initials, $s = tv$.

It follows from this, that $t = \frac{s}{v}$, and $v = \frac{s}{t}$; or,

2. The *time* equals the *space* divided by the *velocity;*

3. The *velocity* equals the *space* divided by the *time.*

17. *Questions on uniform motion:*

1. A body moves uniformly during 21 seconds, with a velo-

Why can we not perceive our *absolute* motion? What is *uniform* motion? *Accelerated? Retarded?* Define *velocity.* Rule for *space* in uniform motion. Give the formula for *space.* For *time.* For *velocity.*

city of 815 feet per second; what space did it describe? *Ans.* 17,115 feet, or 3 miles, 1,275 feet.

2. How long time will a ball occupy in going 1,260 feet, with a velocity of 18 feet per second? *Ans.* 1 min. 10 sec.

3. At what rate per second must a horse run, to make a mile in 2 min. 40 sec.? *Ans.* 33 feet.

4. How far will a bird fly in 24 hours, at the rate of 15 feet per second? *Ans.* $245\frac{5}{11}$ miles.

5. In what time could a man go round the earth (25,000 miles), if he averaged 40 miles per day? *Ans.* 1 y. 260 d.

6. At what velocity per hour must the wind blow, to pass over 4,224 miles in 8 days? *Ans.* 22 miles.

18. *Momentum.*—The momentum of a body signifies *its quantity of motion*, and is reckoned according to the number of particles moving, and the velocity with which they move. Momentum is, therefore, proportioned to the quantity multiplied by the velocity, and may be expressed by the equation, $m = qv$. Hence, $q = \frac{m}{v}$, $v = \frac{m}{q}$; that is,

1. The *momentum* equals the *quantity* of matter multiplied by the *velocity*.

2. The *quantity* of matter equals the *momentum* divided by the *velocity*.

3. The *velocity* equals the *momentum* divided by the *quantity* of matter.

19. A body at rest, however massive, has no momentum; but let it move with very little velocity, and it may have a great momentum, because the quantity of matter is so great. Thus, the greatest ships are crushed like egg-shells between icebergs.

Define *momentum*. To what is it proportioned? Give the formula for *momentum*, also for *quantity* and *velocity*. State the same in *language*. If a great mass of matter is at rest, has it any momentum?

A large cannon-ball, when nearly spent, has been known to take off the leg of a soldier, who attempted to stop it. On the other hand, a small mass of matter may have great momentum, owing to its immense velocity. Hence the effectiveness of balls used in modern warfare, compared with the large timbers and stones thrown by the ancients; for, by the use of gunpowder, we can impel bodies with far greater velocity than the ancient warriors could.

Momentum cannot properly be expressed either in pounds, or in feet; and, therefore, it is customary to use the word *foot-pounds* in measuring momentum.

An impulsive force is measured by the momentum which it produces or destroys. Thus, a blow which gives a momentum of 100 foot-pounds, is *five* times as great as one which gives only 20 foot-pounds.

20. *Questions on momentum:*

1. How much does the momentum of 75 pounds, moving at the rate of 42 feet per second, exceed that of 93 lbs., at the rate of 28 feet per second? *Ans.*—546 ft. lbs.

2. Compare the momenta of two balls, whose weights are 12 lbs. and 16 lbs., and their velocities respectively 45 ft. and 30 ft. per second. *Ans.*—9 : 8.

3. How swift must a 32 lb. ball move, in order to have a momentum equal to that of a battering-ram, whose weight is 10,000 lbs., and velocity 20 ft. per second? *Ans.*—6,250 feet.

4. Suppose one grain of matter, having a velocity of 192,000 miles per second, to stop by its momentum an iceberg moving

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In what *two* ways may the momentum of a body be very great? Give illustrations. Why are the missiles used in modern warfare more effective than those of the ancients? What word is used in measuring momentum? What is the measure of an impulsive force?

one foot per second; what is the weight of the ice? (7,000 grains = 1 lb. av.) *Ans.*—144,822.857 lbs.

21. *The three laws of motion.*—All the facts relating to motion are found to be in accordance with three first principles, which are to be regarded as the *axioms* of mechanical science.

Sir I. Newton

1. The law of *inertia.* A body at rest tends to remain at rest; and a body in motion tends to continue in motion uniformly, and in a straight line.
2. The law of *co-existence of motions.* If several motions are given to a body, the final result is the same, whether they are given at once, or successively.
3. The law of *action and reaction.* To every action there is an equal and contrary reaction.

The truth of these laws is learned not so much by direct experiment, as by a careful study of motion in general. All experiments must, in some degree, fail, because gravity, friction, and the resistance of the air, interfere with them. In proportion, however, as these obstructions are diminished, the more nearly do facts accord with the laws above stated.

22. *First law.*—One part of this law is, that if a body is *at rest*, it tends to remain at rest. Many familiar facts might be referred to, in proof of this. If a horse suddenly starts forward, the rider is apparently thrown backward, though in truth he only tends to remain where he was before the horse started. So, if a man stands in a boat, a quick push of the boat causes him to stumble backward, that is, to remain in his former place.

If one block lies at rest upon another, the lower one may be driven out from beneath, by a quick stroke, thus showing that the upper one inclines to remain at rest. If, however, the lower

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State the *first* law of motion. The *second.* The *third.* How are these laws established? Illustrate the tendency of a body to remain at rest,—on a horse,—in a boat. Experiments with two blocks.

block is pushed along slowly, the friction between the two is a sufficient force to carry the upper one with it at that slow rate. It is because the friction is too small a force to produce so great a momentum, that it gives way in the case of a quick stroke. In like manner, if a horse harnessed to a loaded wagon, makes a sudden spring, he breaks the harness, and leaves the wagon in its place. Here, the strength of the harness is not great enough to communicate to the load all the velocity of the horse, though, if he had drawn gently, the strength would have been sufficient to produce the less momentum. A stone thrown with a moderate velocity through a window, shatters a whole pane, while a bullet fired through it, makes a clean round aperture, without fracturing the rest of the glass. Here, it is the force of cohesion between the particles of glass, which is a sufficient force to carry along all parts of the pane with the small velocity of the stone, but fails to communicate the vastly swifter motion of the bullet. We thus learn how to apply force, in order to produce any desired effect. If a small thread were attached to a weight, and we wish to *break the thread* without disturbing the weight, a very sudden jerk upon the thread is likely to do it. But if we wish to *give motion to the weight*, without breaking the thread, we must draw very gently, and communicate velocity to the weight by small degrees. Quick, violent motions are likely in general to produce separation or fracture, especially where large masses are concerned; while gentle motions will more probably communicate small velocities to the whole, without disturbing the parts. All such examples are illustrations of the principle, that *momentum* is the measure of *force;* so that if a force is small, the momentum which it produces in a given time is small;

Why does a sudden motion of the horse break the harness? Experiment of the bullet. How must force be applied to produce separation?

and the greater the mass to be moved, the less must be the velocity communicated to it by the force.

23. Another part of the first law is, that bodies in motion tend to *continue their motion at the same rate.* When a horse suddenly halts, the rider is likely to be thrown over his head. If a boat is stopped by a collision, the passengers are pitched forward. In each case, the persons tend to continue in motion. That this motion tends not only to continue, but to be straight and uniform, is seen, when a ball is rolled on smooth and level ice. Gravity exerts no direct influence to stop it; and the friction is small, so that the ball continues to move straight forward a great distance; yet there is some friction, and some resistance of the air, and these produce a gradual retardation, and at length cause it to stop.

24. The most satisfactory proof, however, that bodies in motion tend to continue in that state, is derived from our unconsciousness of our own motion along with the earth. Were there not a tendency in our bodies to continue on, as they are now moving with the earth, we should need to make constant exertion to keep up with it, or should at least *feel* which way we are going. But so far is this from being true, that many centuries passed away, before astronomers would accept the doctrine of the earth's motion; and it was regarded as the only fixed and stationary body in the universe.

25. As a matter of observed fact, bodies do not generally move in *straight lines*, but in curves. A stone thrown by the hand, or a ball fired from a cannon, describes not a straight line,

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How in order to move a large mass together? State the second part of the first law. Illustrate by rider. Also, by passengers in a boat. Tendency of a ball when rolled. Are we conscious of our own motion with the earth? What does this prove? *Do* bodies in fact generally move in straight lines? What is inferred?

but a peculiar kind of curve. The earth, and all the planets, describe curved orbits, nearly circular, about the sun. How then, it may be asked, does it appear that bodies tend to move in *straight lines?*

The answer is this: wherever a curve is described, it is found that there is a *force*, operating to turn the body out of the straight line in which it tends to move; and when it is possible for us to remove this force, the body pursues that straight line. In the case of projected bodies, and the planets, the force, which turns them out of a straight line, is *gravity*. When a body is left unsupported, gravity causes it to move toward the center of the earth; if the same body is thrown horizontally, this force of gravity will bend its path from a horizontal straight line into a curve, which turns more and more *towards* the earth's center. So, gravity to the sun turns every planet and comet from a straight line into a curve, which bends *toward* the sun.

26. Let a wheel be revolved on an axis; every particle of it is made to move in the circumference of a circle, because it is compelled by *cohesion* to keep at the same distance from the axis. If we can sufficiently weaken this cohesive force, the particles will show their tendency to move in straight lines, which are *tangents* to the circumference. Thus, let some water be applied to the rim of a wheel; then when the velocity is sufficiently increased, the adhesion of the water to the wheel gives way, and the particles fly off in straight lines, drawn in the directions in which they were moving at the instant of their leaving. This shows the *inertia* of the water, that is, its tendency to *continue* moving in the direction of its present motion. So,

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What force usually turns bodies out of a straight line? What force turns the particles of a revolving wheel out of a straight line? What is the effect of swift revolution, if water is placed on the circumference? Illustrate inertia by the sling.

when a stone is whirled swiftly in a sling, and then released from the action which held it in, it flies off with great velocity in a tangent to the circle which it was describing.

27. *Projectile, centrifugal, and centripetal, forces.*—When inertia is thus manifested in tending to produce motion in the *tangent* to the curved path of a body, it is called the *projectile force;* and this same tendency, so far as it is directed exactly *from* the attracting center, is called the *centrifugal force.* On the other hand, the force (whether it be gravity, cohesion, or any other force) which deflects the body from a straight line, is called the *centripetal force.* Thus, when a ball is fired, the energy of the powder is the projectile force; and gravity, which bends the path of the ball toward the earth, is the centripetal force; while the centrifugal force is only so much of the projectile, as exactly opposes the centripetal.

Fig. 8.

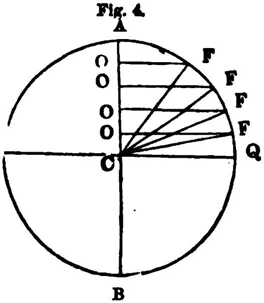
28. The effects of centrifugal force are shown in many ways. When a horse goes swiftly round in a circle, this force renders it impossible to keep on the path, unless he leans inward, so that gravity may operate in part to counteract the outward tendency. For the same reason, the outer track of a railroad curve is placed higher than the inner one, in order that the cars may lean to the concave side of the curve. When a ball is whirled about a center by a thread, it is the centrifugal force which *strains* the thread;

When is inertia called a *projectile force?* That part of the projectile force, which is directed from the centre of rotation, is called by what name? What is *centripetal force?* Illustrate centrifugal force. Horse in the circus. Railroad track. When a weight is whirled by a thread, what force strains the thread?

and if the velocity is so much increased, that this force exceeds the *strength* of the thread (which is the centripetal force), the thread breaks, and the ball by its own *inertia* (the projectile force) flies off in the tangent in which it was moving at the instant the thread broke. Let a vessel containing a little water, be suspended by a cord, as in Fig. 3. After twisting up the cord, its force of torsion causes it to untwist; and as the velocity increases, it will be perceived that the surface of the water becomes hollow, the particles being carried out by the centrifugal force more and more to the circumference, and piled up there, in spite of the force of gravity.

29. The effects of centrifugal force are seen in the form which is given to the planets, by revolving on their axes. Instead of being *spheres*, which is the form that the force of gravity alone would give them, they are *oblate*, or flattened *spheroids*, the shortest diameter being that on which they revolve, called the *axis*. Thus, the earth's diameter through its poles, is 26 miles less than in the plane of its equator; and Jupiter and Saturn, which revolve much swifter, are much more oblate than the earth. Let A Q B (Fig. 4) represent the earth, A B its axis, Q a point on the equator, and F, F, different points between the pole and equator. As the earth revolves on A B, Q will describe a circumference whose radius is Q C, while the radii of those described by F, F, are F O, F O, being shorter, according as they are nearer the pole. The centrifugal force at

Fig. 4.

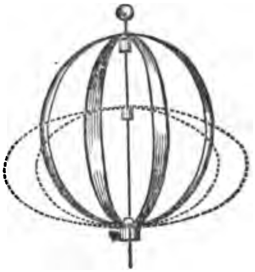


How does the weight move if the thread breaks? What is the form of the *planets*, and why? Explain by Fig. 4, how the earth becomes oblate.

each of these points tends to weaken the force of gravity, and thus to diminish weight, but not equally. At Q, gravity is diminished most, because the velocity is greatest, and also because the centrifugal force directly opposes gravity. But at F, the particles move more slowly, and therefore have less centrifugal force; moreover, as gravity acts toward C, while the centrifugal force acts away from O, instead of C, they only partially oppose each other. So far as the centrifugal force does oppose gravity, it diminishes weight, but the other part of its effect is, to cause the particles to slide towards Q, and thus to accumulate the matter about the equator. It is found by calculation, that the earth would need to revolve seventeen times more swiftly than at present, in order to destroy the whole force of gravity at the equator.

30. The effect of changing a spherical to a spheroidal form can be shown experimentally, by revolving a body whose parts are movable among each other. Thus, a ball of clay on a potter's wheel, will, on being whirled, become oblate. Fig. 5 represents an instrument, consisting of two rings of elastic metal, placed upon an axis. While at rest, these may represent the meridians of a *sphere;* but when made to rotate, they assume the elliptical form of the meridians of an *oblate spheroid*, as shown by the dotted lines.

Fig. 5.



31. *Second law.*—The law of *co-existence of motions* is usually called the law of *composition of forces*, and will form the

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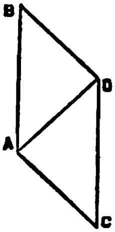
How swiftly must the earth revolve, that bodies on the equator may lose their weight? What is the effect of whirling clay on the potter's wheel? Describe the instrument for illustrating oblateness. State what is meant by co-existence of motions.

subject of Chapter II. It is only necessary here to state what is meant by it, namely: that every motion which is given to a body exists independently of other motions; so that we may determine the final result of several motions given at once to a body, by supposing one motion to exist alone, then the second alone, and so on to the last. For example, in Fig. 6., suppose a ship at A should be carried north by a wind to B, in one hour; after reaching B, let a current move it in one hour southeast to D. Now, instead of these two successive motions, let the ship, when she starts from A, be under the influence of wind and current *both at once;* then, in one hour, she will go direct from A to D. The two hours' work will have been done in the same hour. The current alone, if acting *first*, would have carried the vessel to C; but she is at D, an hour's motion north of C. If the wind had acted first, it would have carried her in an hour to B; but she is at D, an hour's motion southeast of B. The fact that motions thus *exist together*, and produce a result just the same as if they had occurred successively, is fully established by observation. If, on the deck of a vessel at its highest speed, a ball is rolled to a mark, it hits it just as exactly as if the vessel were at rest; but it would not do so, unless the ball had all the motion of the ship, and also the motion which the person gave it. In like manner, when a man standing on the ground fires a ball at a target, this motion of the ball exists entirely independent of the earth's motions. If the earth were *at rest*, then the motion given to the ball by the rifle is its *absolute* motion, since it

Fig. 6.



Illustrate by a ship's motion, by wind and current. Wind first, then current. Current first, then wind. Both together. Illustrate by ball rolled on deck. By the firing of a ball, while the earth moves.

has no other. But, as the earth is really moving, the motion from the rifle to the target is simply superadded to the other motions which it before had, both around the earth, and around the sun; and it could not hit the mark, unless it retained those motions which it previously had, along with the earth. If a body is thrown perpendicularly upward, it comes back again into the hands, though, during its absence, both the ball, and the one who threw it, may have moved hundreds of feet eastward in the diurnal revolution.

32. *Third law.*—The law of *equal action and reaction* may be stated thus: whenever one body acts on another, the second acts just as powerfully on the first, and in the opposite direction. If a ball in motion strikes against another at rest, it not only gives motion to it, but receives from it an impulse backward, which destroys a part of its own motion. A boatman pushes against the shore with a pole, and by the reaction his boat is pushed away from the shore. And, after leaving the land, he continues his motion by pressing the water backward with the blade of the oar, while he is carried forward by the reaction of the water. The swimmer, also, makes progress in a similar manner, by the reaction of the water, against which he strikes. All the movements of fishes in water, and of birds in air, are made by the same means. Indeed, no animal can, by its own agency, move from one place to another, except by the reaction of that against which it acts. Walking and running are accomplished by a succession of backward strokes with the feet against the earth.

33. The injuries resulting from reaction are just as serious as

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Case of a body thrown upward. State the *third law.* Illustrate by balls. How does a boatman move his boat? Swimming. Fishes and birds. In what way alone can a person move from his present place? Which injures the most, action or reaction?

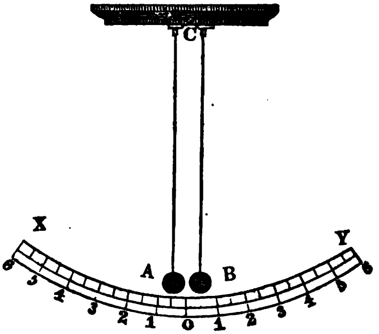
those from direct action. If a person, in running, strikes another who is standing still, the injury to himself is likely to be as great as to the other. If a train of cars, moving at 40 miles an hour, strikes an equal train at rest, it sustains the same damage as if it had been still, and the other had struck it with the same velocity, or, as if each had been moving at 20 miles an hour. If a person is hurt by falling, or running against an obstacle, the injury comes wholly from reaction. The blow of the pugilist harms the face of his opponent more than it does his own fist, not because action is greater than reaction, but because the fist is better able to bear a given blow than the face is.

34. The injury resulting either from action or reaction may be diminished to any degree by extending the time of its application. If a person jumps from a building upon a yielding substance, like a pile of loose shavings, the action, and therefore the reaction, is the same as when he jumps upon a rock; yet, in the first case, he may sustain no harm; in the last, he is in danger of being killed. The reason is, that when he jumps on a hard surface, the entire reaction occurs in an instant; but when he strikes the soft substance, the reaction takes place by degrees; he moves *along with* the substance after meeting it, and loses his motion by little and little. It is like dividing up a severe blow into a great number of successive small blows. There is a similar diminution of injury where a blow is distributed over a large *surface*. Thus, a blow spread over the whole hand produces less pain, than when concentrated upon a small portion of it.

Illustrate by two trains of cars. Why does the face suffer more than the fist, when a blow is given? What is the effect of extending the *time* of a blow? Jumping on a rock, and on shavings. What does the last resemble? Effect of spreading a blow over a large surface?

35. Action and reaction in the case of collision may be accurately measured, by using the instrument represented in Fig. 7. The balls A and B are suspended by long threads, so as to swing by the side of the graduated arc X Y. If one of them is raised to a certain point of the arc, and then let go, its velocity at the bottom, where it strikes the other ball, will be measured by the distance through which it has swung. Suppose the balls to have no elasticity, and first, let them be of equal weight. If A falls from the point 4, and B is at rest, they will go on together, to the point 2; that is, each ball will start from the lowest point with the velocity, 2. Thus B has *received* the motion 2, and A has *lost* the same; the action and reaction are equal. If A strikes with the velocity 6, it will lose 3, and B will receive 3; and the result will be similar in case of any other velocity. Again, let A and B be unequal. We must now measure the action and reaction by the *momentum* gained and lost. Suppose A=2 and B=1. If A is dropped from the point 6, the balls will go to the point 4 on the opposite side. B thus receives the momentum 4 × 1, while A loses 2 × 2. Thus, whatever the various weights and velocities may be, we shall find that the momentum *gained by B* is no more and no less than the momentum *lost by A*. And this is found

Fig. 7.



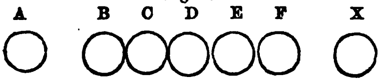
Describe the instrument for collision. How is the velocity measured? Describe an experiment with *equal* balls, not elastic. Another. *Unequal* balls. How must the action and reaction be measured? How much does B always gain?

to be equally true, when *both* bodies are moving, whether in the same or in opposite directions.

36. If the balls are *elastic*, the results of collision are very different from the foregoing; but still the action and reaction remain equal. For B gains *twice* as much as when it was inelastic, and A loses twice as much; so that loss and gain are still equal. For example, if A=B, and falls from 4, then instead of both proceeding to the point 2, as before, B goes to 4, and A remains at rest; thus B receives velocity 4 instead of 2, and A loses all its velocity 4, instead of losing only 2. As in this case, so in all cases of equal elastic bodies, each takes the former velocity of the other. This double loss and gain, in the case of elastic bodies, results from the rebound which occurs when the balls, after being compressed, restore themselves to their original form.

37. Let a row of equal elastic balls (Fig. 8) be suspended in a straight line, touching each other, and let A swing against B, then only the last one, X, will move, and it will take the former velocity of A. For if B were alone, and A should strike it, A would stop, and B would move as swift as A did before the stroke. But the velocity with which B tends to start is all communicated to C, and B then tends to remain at rest; so of C to D, and thus to the last one, X, which therefore moves on, as though A had impinged directly against it, while all the others remain at rest.

Fig. 8.



38. In a great multitude of cases, the *direct* effect of action is wholly imperceptible, and only the *reaction* is observed. This

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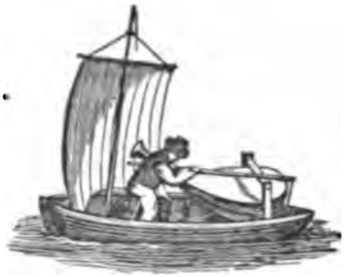
Does the law hold good in case of *elastic* balls? Show how. Why is the loss and gain doubled when the balls are elastic? State and explain the experiment of a *series* of equal balls. When is the direct result of action *imperceptible?*

is because the mass of matter in the body acted upon is very great. Thus, a rope passes from the deck of a large ship to a small boat at a distance, and a sailor in the ship or boat (it is immaterial which) pulls upon the rope, and draws the boat towards the ship. The ship appears to remain at rest, merely because she is so massive that her velocity is too small to be noticed. If the *weight* of the ship is 100,000 times that of the boat, then her *velocity* is 100,000 times less; so that her motion is imperceptible, and yet the momentum of the one is equal to that of the other. Much more will the motion be imperceptible, when action is applied to the *earth*. If a man springs up from the ground, his muscular exertion *separates the two bodies* with equal momenta; the earth therefore really moves, but its velocity is as many times less than his own velocity, as its mass is greater than his. Of course, the earth's velocity cannot be perceived, though it can be expressed by figures. It is in this sense, and in this sense only, that the earth, the mountains, &c., are called immovable.

39. It is to be observed, that the law applies to *every species of action;* such as collision, pressure, drawing by a rope or other means, attraction, repulsion, &c. Thus, the elasticity of gas generated by the burning of gunpowder drives the balls in one direction, and the gun with an equal *momentum* in the opposite. If a magnet and a piece of iron, equal to each other, and mounted alike, are floating on water, they will move toward each other with equal velocities. And when a stone falls to the earth, the earth moves to meet the stone.

Case of boat and heavy ship. How small is the ship's velocity? Which has the greatest momentum? What is the effect of action applied to the earth? In what sense is the earth immovable? To what *kinds* of action does the law apply? Illustration of ball and cannon. Magnet. Fall of a stone.

Fig. 9.



40. All the actions and consequent reactions which take place within a body or system of bodies, necessarily neutralize each other, and give no motion to the body or system as a whole. A child who steps into a basket, and tries to lift himself, only labors in vain; the action of the hands upward, and the reaction of the feet downward, are equal and opposite forces. So, the man in the boat (Fig. 9), who is endeavoring to sail by means of a wind from the bellows on board, can distend the sail, and produce pressure on the mast; but the boat will not advance, because the air driven from the bellows presses them backward as much as the sail forward.

CHAPTER II.

COMPOSITION AND RESOLUTION OF MOTION.

41. If motion is produced by two or more impulses, acting in different directions, it is usually called *compound motion;* and yet it is always true, that a single impulse, if of the right magnitude, and in the proper direction, might have produced the same motion.

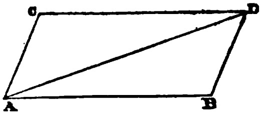
Effects on a body or system of all actions *within* it. Illustrate by child in a basket. By boat with bellows on board. What is meant by compound motion?

The separate impulses, which act on a body at once, are called *components*, and the motion which is produced by their joint action is called the *resultant*. Sometimes the word *resultant* is used to signify that impulse, which would have produced the same effect as the components. When straight lines are used to represent forces, it is understood that they are in the *direction* of those forces, and have the *same ratio* as the forces.

42. *The parallelogram of forces.*—This is the name which is given to the relation between two components and their resultant, and may be expressed in these words:

If the two adjacent sides of a parallelogram represent the two forces which act on a body, the diagonal between them will represent their resultant. Thus (Fig. 10), if A C and A B, the adjacent sides of A C D B, represent two forces which act on a body at A, then A D, the diagonal between them, represents their resultant. In other words, if a certain force would move a body over A C in a given time, and another force would move it over A B in an equal time, then if both forces act at once, the body will move over A D in the same length of time. It has been noticed (Art. 31) that this is merely a co-existence of both the motions given to the body. By the force A B, it is making progress from the side A C to the side B D, just as fast as if no other force acted; and by the force A C, it is making progress from A B to C D, just as fast as if *that* was the only force. Thus, by the joint action of both forces, it is in both the opposite sides, that is, at D, at the end of the

Fig. 10.



Define *components*, and *resultant*. In what respects do straight lines represent forces? Give the law for the resultant of two forces. Explain by Fig. 10. Show that both motions coexist.

given time; and it must have moved straight and uniformly from A to D, because no force acts after leaving A.

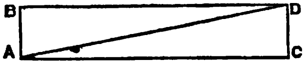
43. *A triangle used instead of a parallelogram.*—For purposes of calculation, it is more convenient to use one of the triangles, A C D, or A B D, rather than the parallelogram. For C D may be used to represent the same force as A B does, since it is equal to it, and in the same direction. Therefore, if A C and C D represent the components, the third side of the same triangle, A D, represents their resultant. Or, if A B and B D represent the components, A D represents their resultant. In constructing the triangle of forces, care must be taken that the *supplement* of the angle between the forces, and not the angle itself, should belong to the triangle. The angle between the forces is C A B; that angle, however, does not belong to either triangle, but its supplement, A C D, belongs to one, and A B D to the other.

44. *The greatest and least values of the resultant.*—It is obvious, that if the angle C A B is made smaller, while the sides of the parallelogram remain of the same length, the diagonal becomes longer, and when the angle becomes *zero*, the diagonal coincides with A B and B D, and equals their sum. On the contrary, as the angle enlarges, A D diminishes, until, when A B and A C are in opposite directions, A D equals their difference. It follows that the resultant of two forces is equal to *their sum*, when they act in the *same* direction, and to *their difference*, when in *opposite* directions; and that it may have any value between these limits.

Show how a triangle may be used to represent two components and their resultant. Does the angle between the forces belong to the triangle? What angle does belong to it? How is the resultant changed, if the angle between the components is smaller? When is the resultant greatest, and how great? When is it least, and how small?

45. *Experimental proofs.*—It is not easy to illustrate accurately the composition of two forces by experiment; but there is no difficulty in showing that a body, when impelled in two directions, takes an *intermediate direction*, and goes faster as the directions are more nearly coincident. Let a ball lie on a level table, and snap it in two directions at once, and it will move in neither of them, but in a direction between the two, and nearest to that of the smartest blow; and by varying the angle of the two impulses, it will be seen to move faster as the angle is smaller, and slower as it is larger. The only complete and satisfactory proofs of the principle are to be sought in the various movements which may fall under our observation. In a ship's cabin, two persons on opposite sides can toss and catch a ball with the same accuracy, when the ship is under full sail, as when at rest. But this could not be, if the ball did not describe the diagonal of a parallelogram, whose two sides are the motion of the ship, and the motion given by the hand, and in exactly the same time. Thus (Fig. 11), let A throw the ball across the cabin to B, but, in the mean time, let the cabin and all its contents be carried along, with the ship's motion, a distance equal to A C or B D, so that when the ball is caught, A has moved to C, and B to D. The person, B, therefore, is at D, when he catches the ball; and it must have travelled over the diagonal A D in the same time in which the *hand* would have sent it from A to B, or the *ship* have carried it from A to C. The two motions fully coexist in the motion of the ball. Again, when a ship is

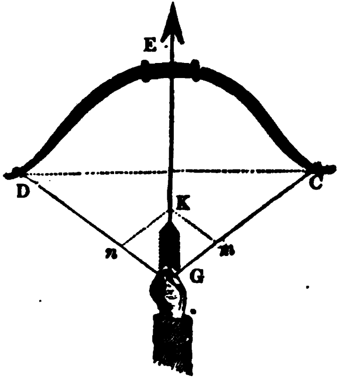
Fig. 11.



How will a ball move on a table if snapped in two directions at once? What is the best proof of the parallelogram of forces? Experiment in the cabin of a ship.

under sail, a stone dropped from the top of a mast is not left behind, but keeps by the side of the mast to the bottom; it thus describes the diagonal of a parallelogram, one side of which represents the motion given by gravity, the other the motion of the ship in the same time. The diagonal in this case, however, is a *curve* line, because the downward motion is not uniform, as will be explained in the next chapter. But the accuracy of the *law* we are considering will appear complete, when we come to compound the small motions which we give to bodies, with the great motion which they already have along with the earth. Suppose a stone is thrown at a mark 100 feet distant, and hits it in one second. During that second the mark moves 19 miles in the path of the earth about the sun, and therefore the stone must have done exactly the same, or it could not have reached the mark.

Fig. 12.



46. It is very common to produce motion by two oblique forces, instead of one direct force. The arrow (Fig. 12) is projected in the line G E by two forces of the string, one represented by G *m*, the other, equal to it, represented by G *n*; their resultant is G K. The wings of a bird strike obliquely backward, and therefore the reaction of the air upon the wings is oblique. In Fig. 13, let the reaction against

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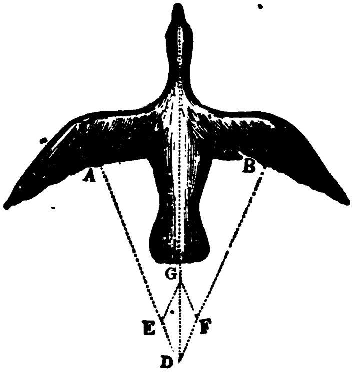
Of a stone falling from the top of a mast. Show how the small motions which we produce are compounded with the motion of the earth. By how many forces is the arrow projected? Explain. Apply the same principle to the flying of a bird.

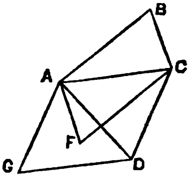
Fig. 13.



the wing A, be represented by D E, and that against B, by D F; their resultant is D G, which is therefore the direction in which the bird is impelled. In a similar manner, a boat is propelled by two simultaneous strokes of the oars, made in oblique directions. If one wing of the bird ceases to act, or one oar of the boatman, the motion produced by the other is round and round, and not forward.

47. *The polygon of forces.*—If more than two forces act at once on a body, the resultant is determined still by means of the parallelogram of forces. First, find the resultant of two forces, then the resultant of this resultant and the third force, and so on to the last. Let the body A (Fig. 14) be acted on by three forces, one of which, acting alone, would carry it over A B; another, A F; and the third, A G, in the same time; it is desired to find what line the body will describe if they all act at once. Constructing the parallelogram A B C F, we find the resultant of A B, A F, to be A C. Now, supposing A C to represent a single force, compound it with A G, by completing the parallelogram A C D G; the diagonal

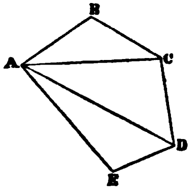
Fig. 14.



Also to the rowing of a boat. When more than two forces act at once on a body, show how the parallelogram of forces is employed. Give the rule for the resultant of *several* forces.

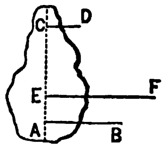
A D is their resultant. Therefore, A D is the resultant of the three forces. Since B C is equal and parallel to A F, and C D to A G, the three forces may be represented by A B, B C, and C D, while their resultant is represented by the fourth side of the same polygon, A B C D. Hence, *the several forces which act together on a body may be represented by all the sides but one of a polygon, and their resultant by the remaining one.* In Fig. 15, if A B, B C, C D, D E, represent forces acting at once on a body at A, the body will describe A E, in the same time in which it would have described either of the other sides by the corresponding force, acting alone.

Fig. 15.



48. *Parallel forces.*—If two forces act together in the same line, we have seen (Art. 44) that their resultant equals their sum. The same is true, when they act *parallel* to each other upon different parts of a body. And, as in oblique forces the resultant makes the least angle with the greatest force, so, when two forces are parallel, their resultant is nearer the greater force. The law of parallel forces, stated fully, is as follows: *when two forces are parallel, their resultant is also parallel to them, and equal to their sum; and its distances from them are inversely as the forces themselves.* Thus (Fig. 16.), if A B and C D act in parallel directions on the same body, their effect is equal to that of *one* force E F, parallel and equal to them, and applied at E, so that E A : E C : : C D : A B. If the parallel forces act in *oppo-*

Fig. 16.



When two forces act in parallel lines, what is their resultant? Nearest to which force? If they are parallel, but in opposite directions, what is the resultant, and where applied?

site directions, then their resultant equals their *difference*, instead of their sum, and is applied outside of the greater force.

49. *Equilibrium of forces.*—When any forces, by their united action, hold any body *at rest*, they are said to be in a *state of equilibrium.* The most obvious case is that of two forces. *Two forces are in equilibrium when they are equal, and act in opposite directions.* Thus, when two men of equal strength pull against each other at the ends of a rope, the forces are balanced. A weight suspended by a cord is acted upon equally, by gravity downward, and the strength of the support upward, and is at rest. *Three* forces are.in equilibrium when they can be represented *by the sides of a triangle, taken continuously.* This follows from Art. 42 ; for, in order that a force may balance two other forces, it must be equal and opposite to their resultant. Hence, as the third side, A D (Fig. 10), represents the resultant of A C, C D, so, if taken in the opposite direction, D A, it must represent the force which is in equilibrium with them. Then the three forces which balance each other are A C, C D, D A ; that is, the three sides of the triangle, *taken continuously.* The same reasoning extends to any number of forces; hence, *all the forces,* acting on a body, are in equilibrium, when they may be represented by *all the sides of a polygon, in continuous order.* Thus (Fig. 15), A B, B C, C D, D E, and E A, will keep A at rest, because A E is the resultant of the other four; and E A, being equal and opposite to A E, will balance it, and, therefore, balance the other four.

50. *Three* parallel forces are in equilibrium, when the middle

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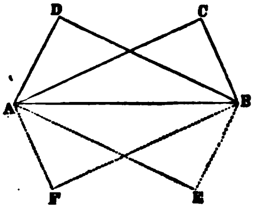
When are forces said to be in equilibrium? When will *two* forces be in equilibrium? Illustrate by two men pulling; by a weight suspended. When *three* forces are in equilibrium, how may they be represented? How, when any number of forces balance each other? When are three parallel forces in equilibrium?

one is in a direction *opposite* to the other two, *equal* to their sum, and at distances from them *inversely proportional* to the forces themselves. For, according to Art. 48, it would then balance the resultant of the other two forces. This case is illustrated, when two persons support a weight on a pole between them. The weight is a downward force, which balances the strength of the two men exerted upward; and it must be placed as much nearer one than the other, as he is stronger than the other.

51. *Resolution of forces.*—This is the reverse of the composition of forces. A certain force being given, the resolution of it consists in finding what two or more forces would produce the same effect. To resolve a force into two forces, we have only to construct a triangle on the line representing the force; its sides will then represent the two components. And, since an infinite number of triangles may be constructed on a given base, a force may, therefore, be resolved into any one of an infinite number of pairs. In Fig. 17, A D, D B, are components of A B; so, also, A C, C B, or the sides of any other triangle which can be made on A B.

Fig. 17.

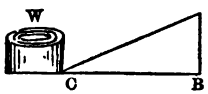


52. To resolve a force into *more than two* forces, we have only to proceed to resolve, as before, one of the two components. Thus, if any triangle be made on A D, whose sides we will call A H, H D, then A H, H D, D B, will be three components, whose resultant is A B. This process may be continued to any extent.

Illustrate by two men and weight. What is meant by the resolution of a force? How is a force resolved into *two* forces? Into how many pairs may it be resolved? How shall we proceed to resolve a force into *three* or any number of forces?

53. *To find the efficient part of a force.*—The resolution of a force is often very important, in order to find how much of it is effective in a certain direction, and how much is without effect. In Fig. 18, the weight W rests on a horizontal plane, and a force C A is applied obliquely upward. The weight cannot move in the direction C A, because gravity confines it upon the plane; and the inquiry is, how much of the force is efficient to move it on the plane. Resolve C A into C B and B A (the latter perpendicular to the plane); then the whole force expended is to the component, which acts along the plane, as C A to C B. The other component, B A, has no other effect than to diminish the pressure on the plane. If $CA=9$, and $CB=7$, then seven-ninths of the force are useful; and, of course, two-ninths are wasted. The two-ninths lost, however, are not represented by B A, but by C A—C B. It is just the same, if the force is directed from A to C, to *push* the weight along the plane. The components are A B, B C; and the last alone is of use; the effect of the first is to produce pressure on the plane. In order, therefore, to prevent waste of power, it should be exerted as nearly as possible in the direction in which the motion is to take place.

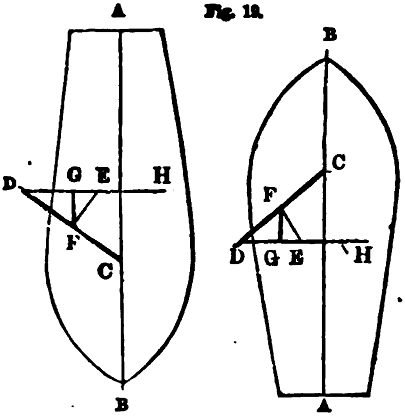
Fig. 18.



54. Sometimes it is necessary to resolve the force, and then again to resolve one component of it, before the effective force is obtained. A good illustration of this occurs in the motion of a sail-vessel. Suppose the wind to blow from the east, while the ship is to go south. Then the sail D C is set as represented in Fig. 19, left hand; while the wind blows in the line H D.

Show how to find the efficient part of a force, when it does not act in the line of motion. What difference of effect in pulling and pushing? How must a force be applied, in order to be as effective as possible? Apply the principle of the resolution of force to the sailing of a ship.

Fig. 19.



Take E D for the force of the wind, and resolve it into E F, perpendicular to the sail, and F D, parallel to it. Now, a force, parallel to a surface, cannot press any against it; hence E F is the only force against the sail. But the ship is not to go in that direction, but in the line A B; therefore resolve E F into E G, perpendicular to A B, and G F, parallel to A B. The last component, G F, is the only one which acts in the right direction. The component E G tends to push the ship sideways, but is nearly prevented from doing so by the form of the keel. While one ship sails *south*, another can sail *north* by the same wind, if her sail is set as in the right-hand figure. The process of resolving is similar to that in the former case. If it were desired to sail toward the *east* while the wind blows *from* the east, then the ship must be steered alternately northeast and southeast. This is called *tacking*.

55. The manner in which a kite is held at rest in the air by the wind, the string, and its own weight, is best explained by resolving the forces into corresponding components. In Fig. 20, let the force of the wind be represented by D F; the kite assumes the oblique position A F, in consequence of the manner

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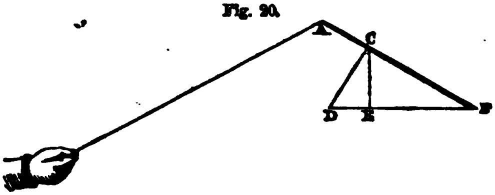
How can the same wind carry two ships in opposite directions? What is *tacking*, and when employed? What forces hold a kite in the air? Apply the resolution of forces to this case.

of attaching the string. The force D F is resolved into D C, perpendicular, and C F, parallel to the kite; the latter has no effect. The former is again resolved into D E, horizontal, and E C, upward. Next, resolve the oblique force of the string into horizontal and downward; then the kite will rest, when the horizontal component of the string balances D E, and its downward component, together with the weight of the kite, balances E C.

Fig. 20.



It is often necessary to resolve one or more forces, in order to find the relation of power and weight in a machine.

CHAPTER III.

ACCELERATED MOTION.—FALLING BODIES.

56. It has been noticed, in considering the subject of inertia, that if a body is put in motion, and left to itself, its motion is uniform. Whenever, therefore, we perceive a body having either an *accelerated* or a *retarded* motion, we infer that it is constantly acted on by some force, which hastens or hinders it. The action of gravity furnishes the most familiar examples of

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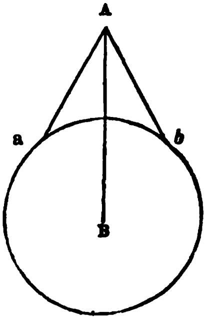
If a body has an *accelerated* or a *retarded* motion, what is inferred? What force furnishes familiar examples?

these variable motions. When a body is left unsupported, gravity in the first instant urges it toward the center of the earth; it therefore begins to move in that direction, and if the force should immediately cease, the body would proceed at a slow and uniform rate. But, in the next instant, gravity acts a second time, and the body proceeds with a double velocity, and would continue with this velocity, if gravity should cease at *that* point. But a third impulse triples the velocity, and so on continually. It should be observed, that on account of inertia, the body retains all the motion previously given, and constantly receives new accessions. And, as these impulses are all equal, the motion is uniformly accelerated.

57. As all parts of the earth attract the body, the reason is easily seen, why its motion is directed toward the *center*. For (Fig. 21), the earth being a sphere, while some part, as *a*, attracts the body A in an oblique direction, there is a corresponding part, *b*, which attracts it equally on the other side; and the resultant of these two forces would be directed mid-way between them, that is, toward the center. This reasoning applies to all the corresponding parts of the whole earth. A body, therefore, moves toward the earth's center, not because the *attraction* is all toward the center, but because the *resultant* of all the attractions lies in that direction.

Fig. 21.



58. *Laws of falling bodies.*—From the nature of the force

State how gravity produces acceleration. How would a body move if gravity should cease, while it was falling? Why does a falling body move toward the earth's center?

of gravity, it is proved, that if bodies should fall unobstructed by the atmosphere, they would conform to the following laws:

1. *All bodies fall with the same velocity.*—This is because gravity is proportioned to the quantity of matter in bodies. (Art. 4.) If one body consists of ten times as much matter as another, it needs ten times the force exerted upon it, to give it the same velocity; and the earth *does* exert ten times as much force upon it; hence, both bodies fall with equal speed. This would be the case in a ***vacuum;*** but in the air, all bodies are obstructed in their fall, and those are most obstructed, which present most surface in comparison with their quantity of matter. Therefore, an open sheet of paper falls more slowly than when crushed into a ball; a sphere of cork, more slowly than one of lead of the same size, because it contains less matter within an equal surface; and, of two balls of the same material, the smallest falls slowest, since the surface is not so much less, as the quantity of matter is.

2. *The velocity acquired is proportional to the time spent in acquiring it.*—This is because gravity adds an equal amount of velocity every second, while the body retains that which was previously given. It is found that in *one second*, a falling body acquires a velocity of $32\frac{1}{6}$ feet per second; and if gravity should not act any longer, the body would proceed at that rate uniformly; but as gravity operates during the next second also, another velocity of $32\frac{1}{6}$ feet is added, so that, after the lapse of *two* seconds, the body has a velocity of $2 \times 32\frac{1}{6} = 64\frac{1}{3}$ feet. So, after *three* seconds, the velocity is $3 \times 32\frac{1}{6} = 96\frac{1}{2}$ feet; and after *one minute*, it is $60 \times 32\frac{1}{6} = 1930$ feet.

$16\frac{1}{12} + 32\frac{1}{6} = 48\frac{1}{4}$

2 sec = $64\frac{1}{3}$

What is the *first* law of falling bodies? Why is this true? Is it true in air? Why not? State the second law. Why? What is the velocity acquired in one second? In *two? Three? Ten?* In one-minute?

3. *The space described by a falling body is proportional to the square of the time.*—It is proved by mathematical reasoning, that this law is a consequence of uniform acceleration, whether produced by gravity or by any other means.

In *one* second, a body is observed to fall $16\frac{1}{12}$ feet; therefore, in *two* seconds, it falls $2^2 \times 16\frac{1}{12} = 64\frac{1}{3}$ ft.; in *three* seconds, $3^2 \times 16\frac{1}{12} = 144\frac{3}{4}$ ft.; in *four* seconds, $4^2 \times 16\frac{1}{12} = 257\frac{1}{3}$ ft., &c.

Since time and velocity are proportional (2d law), the *space varies also as the square of the acquired velocity.*

4. *With the acquired velocity continued uniformly, a body moves twice as far, in the same time, as it falls to acquire that velocity.*—This also results from the nature of uniform acceleration. It is illustrated in the case already stated, that a body falls $16\frac{1}{12}$ ft. in one second, and that it acquires a velocity of $32\frac{1}{6} = 2 \times 16\frac{1}{12}$ ft. in one second; for the velocity acquired is the distance which a body would describe in a second with a uniform motion.

59. *A body projected downward.*—Since motions given to a body always co-exist (Art. 31), therefore, when a body is projected downward, it has all the motion which projection alone would have given it, together with that which gravity would cause in the same time. Thus, if a body is thrown down at the rate of 20 ft. per second, it will in 5 seconds pass over 5×20 ft. $+ 5^2 \times 16\frac{1}{12} = 502\frac{1}{12}$ ft.

60. *Uniformly retarded motion.*—As gravity *adds* equal quantities every second to the velocity of a *falling* body, so it *takes away* equal quantities from that of an *ascending* body. Hence, the motion of a body projected upward is uniformly

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State the *third* law. Illustrate it by examples. What is the space in one second? How many times that in *five* seconds? In *nine* seconds? How does space vary compared with acquired velocity? What is the *fourth* law? What motion has a body when projected downward?

retarded, until it stops, and begins to fall. It would therefore require the same time for a body to ascend till it stops, as to descend from rest through the same distance; and the velocity first *given* to an ascending body must be equal to that *acquired* by a descending body, when the whole distance is the same. Thus, all the circumstances of the motion are reversed.

61. *Rules for calculating.*—From the laws of falling bodies now stated, are readily derived the following rules for making numerical calculations on this subject:

1. If the *time* of descent (or ascent) is given, multiply the number of seconds by $32\frac{1}{6}$, to find the acquired (or first) *velocity* in feet; and multiply the square of the number of seconds by $16\frac{1}{12}$, to find the *distance* in feet.

2. If the *velocity* is given, divide by $32\frac{1}{6}$ to find the *time* in seconds; and divide the square of the velocity by $64\frac{1}{3}$, to find the *distance* in feet.

3. If the *distance* is given, divide the number of feet by $16\frac{1}{12}$, and extract the square root of the quotient, to find the *time* in seconds, and multiply the distance (in feet) by $64\frac{1}{3}$, and extract the square root of the product, to find the *velocity*.

62. *Questions on falling bodies.*

1. If rain-drops are 12 seconds in falling, how high is the cloud? *Ans.* 2,316 feet.

2. If a body falls to the ground in half a minute, with what velocity does it strike? *Ans.* 965 feet.

When a body is projected upward, what *kind* of motion has it? Why? What is its first velocity equal to? If *time* of fall is given, how are the space and the acquired velocity calculated? State how to obtain the space and the time of fall, when the acquired *velocity* is given. When *distance* is given, how are time and velocity calculated?

3. *The space described by a falling body is proportional to the square of the time.*—It is proved by mathematical reasoning, that this law is a consequence of uniform acceleration, whether produced by gravity or by any other means.

In *one* second, a body is observed to fall $16\frac{1}{12}$ feet; therefore, in *two* seconds, it falls $2^2 \times 16\frac{1}{12} = 64\frac{1}{3}$ ft.; in *three* seconds, $3^2 \times 16\frac{1}{12} = 144\frac{3}{4}$ ft.; in *four* seconds, $4^2 \times 16\frac{1}{12} = 257\frac{1}{3}$ ft., &c.

Since time and velocity are proportional (2d law), the *space varies also as the square of the acquired velocity.*

4. *With the acquired velocity continued uniformly, a body moves twice as far, in the same time, as it falls to acquire that velocity.*—This also results from the nature of uniform acceleration. It is illustrated in the case already stated, that a body falls $16\frac{1}{12}$ ft. in one second, and that it acquires a velocity of $32\frac{1}{6} = 2 \times 16\frac{1}{12}$ ft. in one second; for the velocity acquired is the distance which a body would describe in a second with a uniform motion.

59. *A body projected downward.*—Since motions given to a body always co-exist (Art. 31), therefore, when a body is projected downward, it has all the motion which projection alone would have given it, together with that which gravity would cause in the same time. Thus, if a body is thrown down at the rate of 20 ft. per second, it will in 5 seconds pass over 5×20 ft. $+ 5^2 \times 16\frac{1}{12} = 502\frac{1}{12}$ ft.

60. *Uniformly retarded motion.*—As gravity *adds* equal quantities every second to the velocity of a *falling* body, so it *takes away* equal quantities from that of an *ascending* body. Hence, the motion of a body projected upward is uniformly

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State the *third* law. Illustrate it by examples. What is the space in one second? How many times that in *five* seconds? In *nine* seconds? How does space vary compared with acquired velocity? What is the *fourth* law? What motion has a body when projected downward?

retarded, until it stops, and begins to fall. It would therefore require the same time for a body to ascend till it stops, as to descend from rest through the same distance; and the velocity first *given* to an ascending body must be equal to that *acquired* by a descending body, when the whole distance is the same. Thus, all the circumstances of the motion are reversed.

61. *Rules for calculating.*—From the laws of falling bodies now stated, are readily derived the following rules for making numerical calculations on this subject:

1. If the *time* of descent (or ascent) is given, multiply the number of seconds by $32\frac{1}{6}$, to find the acquired (or first) *velocity* in feet; and multiply the square of the number of seconds by $16\frac{1}{12}$, to find the *distance* in feet.

2. If the *velocity* is given, divide by $32\frac{1}{6}$ to find the *time* in seconds; and divide the square of the velocity by $64\frac{1}{3}$, to find the *distance* in feet.

3. If the *distance* is given, divide the number of feet by $16\frac{1}{12}$, and extract the square root of the quotient, to find the *time* in seconds, and multiply the distance (in feet) by $64\frac{1}{3}$, and extract the square root of the product, to find the *velocity*.

62. *Questions on falling bodies.*

1. If rain-drops are 12 seconds in falling, how high is the cloud? *Ans.* 2,316 feet.

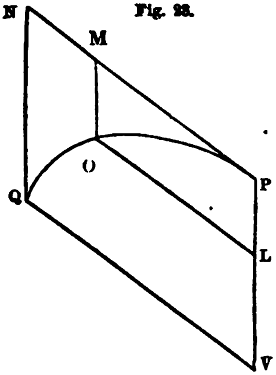
2. If a body falls to the ground in half a minute, with what velocity does it strike? *Ans.* 965 feet.

When a body is projected upward, what *kind* of motion has it? Why? What is its first velocity equal to? If *time* of fall is given, how are the space and the acquired velocity calculated? State how to obtain the space and the time of fall, when the acquired *velocity* is given. When *distance* is given, how are time and velocity calculated?

tions, the obstruction of the air is diminished in a much greater ratio than the velocity; so that the motion is of the *same nature* as if the body were falling freely in a vacuum, (that is, it is *uniformly accelerated*), since the force which causes it acts all the time with the same energy, and without obstruction. When the instrument is constructed with care, the laws of fall, and the law of inertia also, are well illustrated by it.

65. *The path of a projectile.*—When a body is projected in any other than a vertical direction, it describes a curve line of a particular kind called a *parabola*. It is evident that it must be a *curve* of some kind, because, whatever direction the body takes at first, gravity immediately deflects it from that line into a new one, again from that to another, and so on, continually bending the line towards the earth. In Fig. 23, let the impulse given to the body carry it to M, while gravity would carry it to L; then, by the action of both, it will be at O; in like manner it will reach Q, while the impulse would carry it to N, and gravity to V. But the line P M N is described *uniformly*, and P L V, with a *uniformly accelerated* motion; so that, if P M : P N were as 2 : 3, then P L : P V would be as the squares 4 : 9. And it is this relation which proves the curve to be a *parabola*, one of those curves called

Fig. 23.



How much is the resistance of the air reduced? What path does a projected body describe? What two forces act on it? Why must it be a *curve?* Illustrate by figure.

conic sections. The form of the curve is best seen in a jet of water, when thrown obliquely, with a moderate velocity. If the velocity is very great, the resistance of the air causes it to deviate sensibly from the symmetrical form of the parabola.

66. *The science of projectiles.*—In order that a cannon-ball may strike an object at a given distance, it is necessary to know at what *angle* of elevation, and with what *velocity*, it must be discharged. And if the projectile were a shell, it would also be necessary to determine the *time* of flight, so that the explosion might occur as soon as it should strike. If it were not for the obstruction of the air, all these particulars could be determined by exact *calculation* from the properties of the parabola. But, in such swift motions, it is found that the resistance of the air is immense, and the results of theory alone are of little or no value.

67. If the track of the ball were a perfect parabola, the ascent and descent would be made in equal times; the highest point would be over the middle between the ends of the curve; and the ascending and descending branches would be precisely alike. In practice, however, the time of ascent is sometimes greater, sometimes less, than that of descent, according to the elevation; and the descending branch is more nearly perpendicular to the horizon than the ascending one; so that the highest point is beyond the middle of the whole curve. Again, according to calculation, the greatest horizontal range occurs when the cannon is elevated 45°; and, at equal angles above and below 45°, the range is equal, as represented in Fig. 24. But in practice

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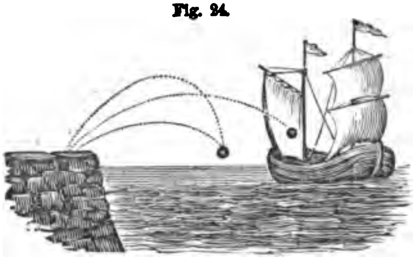
How may the path be well seen? That a cannon-ball may strike a certain object, what must be known? If it is a *shell*, what more must be known, and why? Why do no calculations agree with facts? Where is the highest point of the path? Are the times of ascent and descent equal?

Fig. 24.



the greatest range is always found at an angle below 45°, and the more below it, as the velocity is greater; the elevation being, for the greatest velocities employed, as small as 30°.

On account of these effects of the air, it becomes necessary to determine by experiment what modifications must be made in the mathematical theory, before it can be successfully employed in the practice of gunnery.

CHAPTER IV.

CENTER OF GRAVITY.—PENDULUM.

68. There is in every mass of matter a certain point, about which, if supported, all parts of the mass, when acted on only by gravity, will balance themselves. This point is called the *center of gravity*.

Since gravity acts on all the particles of a body in parallel lines, the laws of parallel forces are employed for determining the place of the center of gravity; for the resultant of all these forces passes through that center. The whole body, there-

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What elevation gives the greatest range in theory? In practice? Define the *center of gravity*. What laws are used for finding its place in a body?

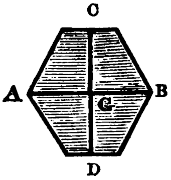
fore, may be considered as collected at the center of gravity, and all the forces exerted by the earth on the several particles, may be compounded into one force acting on that point.

69. The center of gravity of *two equal particles or bodies* is at a point *midway between them.* For (Art. 48), since the two forces are *equal*, the resultant is *half way* from one to the other. From this it follows, that the center of a *series of particles*, arranged uniformly in a straight line, is in the middle of the line.

70. The center of gravity of two *unequal* particles or bodies is as much nearer the greater than the less, as the one is heavier than the other. Here the parallel forces are unequal, and the resultant (Art. 48) is so situated, that its distances from the lines of the forces are inversely as the forces.

71. *In a lamina of matter of regular form*, the center of gravity is in the center of its figure; as in the circle, the ellipse, and the regular polygon. For example, in the regular hexagon (Fig. 25), the center of gravity is at G, the intersection of the two bisecting lines, A B, C D. The same is true of *solids*, having sufficient *regularity of form;* as the sphere, the spheroid, the cylinder, &c. But in the cone or pyramid, the center of gravity is a little higher than the center of magnitude.

Fig. 25.

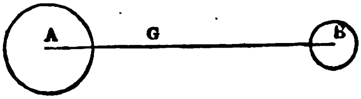


It is supposed in the foregoing cases that the *density is uniform.* If the density is not uniform, the center of gravity is removed toward the denser part.

Where is the center of gravity between two *equal* bodies? Why? What inference as to a line of particles? State the place of the center between two *unequal* bodies. When is the center of gravity in the center of figure? Give examples. What is supposed as to density?

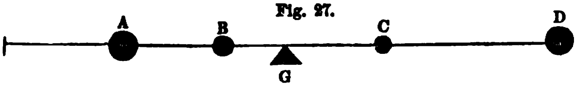
72. *Equal moments.*—Suppose A and B (Fig. 26) to be connected by a rod without weight, and let G be their center of gravity; then $A : B :: BG : AG$. Changing this into an equation, we have $A \times AG = B \times BG$. And since A and B balance about G, they have equal tendencies to descend. Therefore $A \times AG$ and $B \times BG$, may be used to express these tendencies. The word *moment* is used to express the tendency of a force to produce motion about a center; hence the statement, that *two bodies have equal moments with respect to their center of gravity.*

Fig. 26.



73. If more than two bodies are connected by a straight rod without weight (Fig. 27), then their center of gravity, G, will be so situated, that the *sum of the moments on one side equals the sum of the moments on the other;* or, $A \times AG + B \times BG = C \times CG + D \times DG$. For it is obvious that these *moments* (or tendencies to move about G) must be equal, in order that the bodies may balance about that point.

Fig. 27.



74. *Line of direction and base of support.*—The line of direction in any body is the line passing through its center of gravity toward the center of the earth; it is therefore the line in which the center would move by the force of gravity, if the body were unsupported. Hence it is clear, that the line of di-

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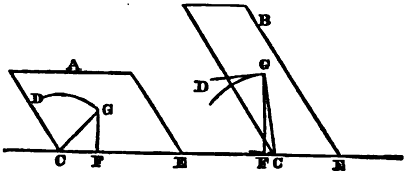
Define the word *moment.* What product expresses the moment? Give the law of moments. Give the equation of moments, when several bodies are on one straight line. Define the *line of direction.*

rection must always pass through the *base of support*, whether that base be an area, a line, or a point; else the body will fall.

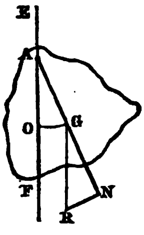
Fig. 28.



In Fig. 28, the body A will not fall, because the line of direction comes *within* the base. If a force were applied to push it over, the center must *rise* in the arc G D. But in the body B, the line of direction falls *without* the base, and one component of the force of gravity will cause the center to *descend* in the arc whose radius is G C, so that the body must fall.

When a person carries a heavy weight, it is necessary (unless it rests on his head) to *lean*, sufficiently to bring the center of gravity of his body and the weight over his feet; as, for example, if the load is in his hand, he leans to the other side; if it is on his back, he leans forward.

Fig. 29.



75. *Stable, unstable, and neutral equilibrium.*—If the base is reduced to a line or a point, still there is *support*, when the line of direction passes through the line or point; but there is no *firmness* of support; the least force will move the body. For example, let the body (Fig. 29) be suspended by the pivot A; then A may be called the base of support; and if the center of gravity is either directly above or directly

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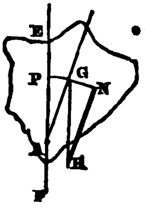
When is a body supported by its base? When not? Explain. Which way needs a person to lean, when carrying a load, and why? When has a body no *firmness* of support?

below A, the line of direction passes through the base, and the body is supported. Yet, in either case, the body will be moved from its place of rest by the slightest force. The two positions of the center, *above* and *below* the pivot A, are, however, very different in one respect. If, in Fig. 29, the center of gravity is *below* A, at the point O, and is swung aside to G, it tends to return again. For, let G R represent the force of gravity, and resolve it into G N, in a line through A, and N R, perpendicular to G N. Then G N cannot move the body, because A prevents; but N R urges it toward A F. After swinging back to O, its momentum carries it to the other side of A F, when there is again the same reason for returning. Thus, it oscillates from side to side. This is called the *stable equilibrium*, because the body, when disturbed from its place of support, always returns to it. Again (Fig. 30), let the center of gravity be at P, *above* the pivot A; it is as truly supported there as at O (Fig. 29), because the line of direction passes through the base A; but if it is disturbed in the slightest degree, it cannot return. For, suppose it moved to G, and that G R represents gravity. Resolve it into G N and N R, perpendicular and parallel to G A; then N R is balanced by the strength of A, and G R moves the body *away from* P, and not towards it. It cannot, therefore, return to its place of support. This is called *unstable equilibrium*. If the center of gravity is so situated that it neither rises nor falls when disturbed, the body has a *neutral*

Fig. 30.



When will the body, if disturbed, return to its place? When not? Explain by resolving force of gravity. What kind of equilibrium is the first? The second?

equilibrium. A sphere of uniform density, lying on a horizontal plane, is an example.

76. To suspend any thing delicately, and yet safely, attention must be given to the position of the center of gravity. A thin magnetic needle is supported so as to have the freest motion, and yet a stable equilibrium, by allowing the standard to pass through it, into a cap on the upper side; thus, the center of gravity hangs below the point of support, and the needle can vibrate without falling. Toy images are so made that they will always keep erect, by loading the lower part, and giving it a broad curvature; the center will then rise, whichever way the figure leans, and be lowest when the figure is upright. Articles are ordinarily hung on pins or hooks by the *upper* part, so as to secure for them a stable equilibrium. But when one balances a tall rod on his finger, or walks on stilts, or on a rope, the equilibrium is unstable, and a constant effort is needed to keep the center of gravity above the base. The person who walks a rope or a wire usually holds a pole, which he moves to one side or the other, for the purpose of restoring the equilibrium.

77. *Finding the center of gravity by experiment.*—The subject of equilibrium furnishes, in many cases, an easy method of finding the place of the center of gravity of a body. For if the body be suspended, the center will settle exactly *below* the point of suspension. Having in some way indicated the line of direction, suspend the body again by a different point, and find the new line of direction; then the center of gravity is at the

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What third kind is there? Example. How is a magnetic needle suspended? Why? How are toy figures made to keep upright? By what part are articles generally hung up? Why? Examples of unstable equilibrium. How does a person aid himself in walking on a rope? Describe how to find the center of gravity by experiment.

intersection of the two lines. For example, if an irregular piece of board were suspended by its edge, first at one point, then at another, and a plumb-line were hung by the side of it, in each case, from the same points of suspension, the two lines could be marked on the surface, and their intersection found.

78. *Firmness of support.*—When the base of a body is an *area*, instead of a line or a point, and the line of direction falls within that area, there is always more or less *firmness* of support, as has been shown (Art. 74). But the degree of firmness depends on the size of the base, and on the height of the center of gravity. If the base is smaller, or the center more elevated, the firmness is less, because the angle is less through which the body can lean, without bringing the line of direction to the edge of the base. Thus, a wagon loaded with hay is more easily upset than when loaded with iron, because the center of gravity is much higher. Observe that, in this case, the *base* of the wagon is the whole rectangle between the four points in which the wheels touch the ground. A single book lying on its side is in no danger of falling over on its edge, because the center is very low, and the base broad; but a pile of books, ten feet high, even if all fastened firmly together, would be liable to fall.

79. *Distribution of supports.*—All questions relating to the distribution of supports, so that they may bear equal portions of the weight of a body, are determined by the laws of parallel forces. As a simple example, suppose (Fig. 31) that one man carries the end, A, of a stick of timber, and two others carry the other end by means of the bar B C, and it is inquired where

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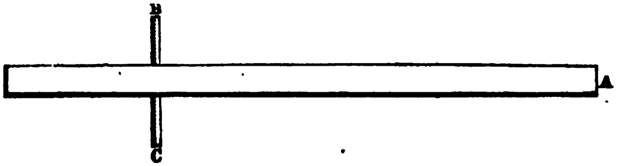
When does a body have *firmness* of support? What does the degree of firmness depend upon? Illustrate by loads. What is the base of a four-wheeled wagon? A book? A pile of books? How shall three men bear equal parts of a stick of timber.

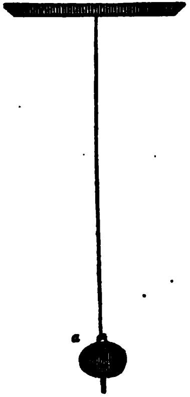
the bar must be placed, in order that B and C may each sup-

Fig. 31.



port as much as A. Consider the whole weight as collected at its center of gravity; then B C must be half as far from the center as A is; for the strength of A is one force, and the united strength of B and C, another parallel force twice as great; therefore (Art. 48) the resultant of these forces will be twice as near to B C as to A, as it ought to be, in order to balance the weight of the beam. All similar questions would be solved on the same principle.

Fig. 32.



80. *The pendulum.*—Whenever a body is so suspended by a point, that its center of gravity is free to oscillate back and forth through the position of stable equilibrium, it may be called a *pendulum*. In the usual construction of the pendulum (Fig. 32), it consists of a heavy disk of metal at the lower end of a slender rod, at the top of which is the point of suspension. The disk has the shape of a double convex lens, with thin edges, that it may be resisted as little as possible by the air. If the pendulum is pushed aside from its lowest position, it returns to it again, and in so doing acquires a momentum, which

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Explain the reason. When does a body become a pendulum? Its usual form? Which kind of equilibrium has it?

is not destroyed by gravity till it reaches the same height on the opposite side. Hence, if no obstruction existed, the vibrations would never cease.

81. *The center of oscillation.*—As the pendulum vibrates, portions of matter in the lowest part have more momentum than equal portions in the upper part, because of their greater velocity. There is, therefore, some point where the momentum is just an average of the whole. That point is called the center of oscillation; it is *below the middle* of the material of the pendulum, so that the less matter of the lower part may compensate for its greater velocity. The *length* of the pendulum is considered to be the distance from the point of suspension to the center of oscillation; because a single particle of matter suspended by a line of that length, and having no weight, would vibrate in the same time.

82. *The laws of the pendulum.*

(1.) *The times of vibration are independent of the extent of swing*, if the arcs are short. Thus, if a pendulum swing through *one degree*, it will make as many vibrations in an hour as if it swings only $\frac{1}{100}$ of a degree, since both arcs are small. If it should be made to vibrate through 30° or 40° the time would be somewhat greater. It is said that Galileo was first led to investigate the laws of the pendulum, by noticing this fact of equal vibrations in the swinging of the great chandelier in the cathedral of Pisa.

(2.)—*The times of vibration vary as the square roots of the lengths.*—For example, if there are two pendulums, whose lengths are 1 foot and 4 feet, the times of swinging will be

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What is the center of oscillation? Why below the center of the matter? What distance constitutes the *length* of the pendulum? State the *first* law. What led to the discovery of the properties of the pendulum? *Second* law. Illustrate it.

as the numbers 1 and 2, the square roots of the lengths; that is, the longer will swing *once*, while the shorter will swing *twice*. So, a pendulum 9 feet long will swing once, while the shortest swings three times. The seconds pendulum is between 39 and 40 inches. Hence, a pendulum to beat half seconds is a little less than 10 inches.

(3.) *The time of vibration varies as the distance from the center of the earth.*—Thus, at a point *four* miles above the earth, a pendulum would require about $\frac{1}{1000}$ longer time to perform a vibration than at the surface, being about $\frac{1}{1000}$ farther from the center. It is by means of this law, that it has been ascertained that the poles of the earth are 13 miles nearer the center than the equator is.

83. *The pendulum as a time-keeper.*—Because of the exactness with which a pendulum performs its vibrations, great use is made of it for measuring time, both for the common purposes of life, and for scientific researches. Since the obstructions to which the pendulum is subject, would at length cause its motion to cease, the mechanism of the clock applies a small force to it at every vibration, so that the extent of swing may not diminish. The contrivance for accomplishing this will be described in the chapter on machinery.

84. As heat expands substances, and loss of heat contracts them, the pendulum in warm weather lengthens, and swings slower, and the reverse in cold weather. In the best clocks this cause of irregularity is removed, by making a more expansible metal elevate the center of oscillation as much as a less

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What is the length of the seconds pendulum? Of a half-seconds pendulum? What is the third law? Give an illustration. What form has the earth, and how discovered? What is the common use of the pendulum? Of what use is the machinery of a clock? How does heat affect the pendulum? In what season does a clock lose time? How is the evil remedied?

expansible one lets it down. In the *gridiron* pendulum the compensation is made by using *brass* rods to elevate, while *iron* rods lower, the center. In the *mercurial* pendulum a cup of mercury performs the compensation, mercury being a very expansible substance. All pendulums which are so constructed as to neutralize the effects of heat and cold, are called *compensation* pendulums.

85. *The pendulum as a standard of measures.*—The English nation, the American, and some others, have made the seconds pendulum their standard of *measures.* It is admirably fitted for this purpose, because of its invariable length at a given place. Should the standard yard of our country be lost or destroyed, it could be restored by adjusting a pendulum so as to beat seconds; and then the precise relation of its length to the standard yard would be known. The standard *weight* is also fixed by the same means, because of the known number of pounds in a cubic foot of water.

CHAPTER V.

THE SIMPLE MACHINES.

86. *Machines* are instruments through which a power operates, in order to *modify its effects* in various ways. A power can produce no *greater* result by means of a machine than without it; but it can produce results in *various forms;* and this is the object of machines. Most of the contrivances employed for such a purpose are reduced to a few elements called

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Describe the gridiron pendulum. The mercurial pendulum. What are machines? Can a power produce *greater* effect with a machine than without it? What is the use of machines?

simple machines. They are the following: 1. *The lever.* 2. *The wheel and axle.* 3. *The pulley.* 4. *The rope machine.* 5. *The inclined plane.* 6. *The wedge.* 7. *The screw.* 8. *The knee-joint,* or *combined levers.*

Compound machines consist of two or more simple machines acting one upon the other.

In the use of a machine, whatever *produces* motion is called the *power*, and whatever *receives* the motion is called the *weight.*

1.—THE LEVER.

87. The *lever* is a bar free to move about a point called the *fulcrum.*

The straight lever.—This is the simplest form, and is of three orders. In the 1st, the *fulcrum* is between the power and the weight (Fig. 33); in the 2d, the *weight* is between the power and the fulcrum (Fig 34); in the 3d, the *power* is between the weight and the fulcrum (Fig 35).

Fig. 33.

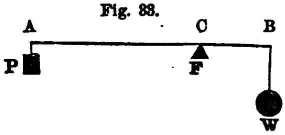
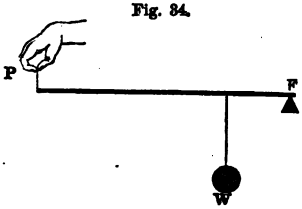


Fig. 34.



88. In Fig. 33, P and W are parallel forces acting *downward,* and the reaction of the fulcrum is a balancing force acting *upward.* Hence, by the law of parallel forces (Art. 50), each is represented by the distance between the other two, so that P : W :: B C : A C; or, *the power and weight are inversely as the lengths of the arms.* Multiply extremes

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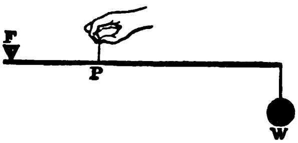
Name the *simple* machines. What are *compound* machines? What is the *power?* The *weight?* Define the *lever.* How many orders of straight lever? Describe. Show the law of the first order by the principle of parallel forces.

and means, and we have $P \times AC = W \times BC$; that is, *the moment of the power equals the moment of the weight.*

From the same law of parallel forces, it is shown that in the 2d and 3d orders likewise (Figs. 34, 35), the power and weight are inversely as the lengths of the arms.

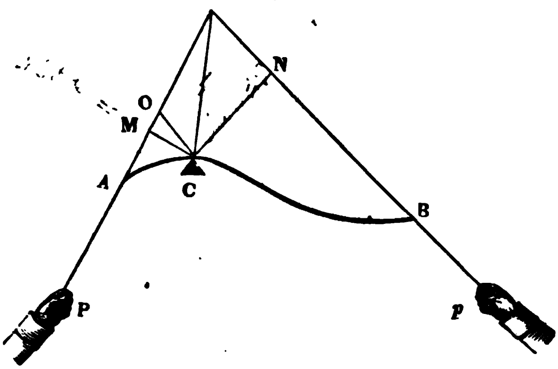
Fig. 35.



When a lever moves, the ends of the arms will have *velocities* which are proportional to the lengths of the arms. Therefore, since the power and weight are inversely as the lengths of the arms, so they will be inversely as the velocities.

89. *General law of the lever.*—If the forces are not parallel, or if the form of the lever is not straight, then the foregoing statement needs to be altered. In Fig. 36, let A C B be a lever

Fig. 36.



What is the *equation?* Give the law for the second and third orders. How are the *velocities* of power and weight proportioned? When the forces are not parallel, what lines in Fig. 36 represent the forces and the pressure on the fulcrum?

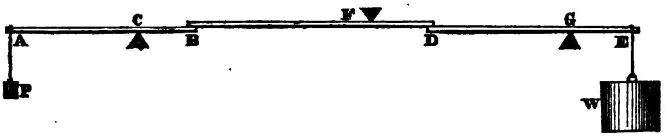
of any form, and suppose the forces to act in the lines A P, B *p*. Produce these lines till they meet in S; join S C, and draw O C parallel to S B. Now, as the forces act in the directions S O, O C, the third side of the triangle S C O, namely, S C, must represent their resultant (Art. 43), in order that it may be counterbalanced by the fulcrum C, when there is equilibrium. Draw C M, C N perpendicular to S A, S B, the lines in which the forces act, and it can be proved that $CM : CN :: OC : SO$. But $OC : SO :: p : P$ (Art. 43); therefore, $p : P :: CM : CN$.

90. The lines C M, C N, drawn from the fulcrum perpendicularly to the lines in which the forces act, are called the *acting distances.* Hence the general law of the lever may be stated thus: *the power and weight are inversely as their acting distances.* This law includes that for the straight lever, because in that, the *arms* themselves are the acting distances.

Making an equation of the proportion, we find $P \times CM = p \times CN$; or, *the moment of the power equals the moment of the weight;* where it is understood, that the *moment* signifies the product of either force by its acting distance.

91. *The compound lever.*—In a compound lever, the effect or *weight* of the first lever is the *power* of the second, and so on.

Fig. 37.



Thus (Fig. 37), the pressure at B is the weight for the lever

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How are the power and weight proportioned? What is the *acting distance?* The *moment?* Give the general law of the lever. Describe the *compound* lever?

A B, and the power for B D, &c. Let the pressure at B be called x, and that at D, y; then $P : x :: BC : AC$;

$$x : y :: DF : BF;$$

$$y : W :: EG : DG.$$

Multiply these proportions together, and divide the first couplet by x and y, and we obtain $P : W :: BC \times DF \times EG : AC \times BF \times DG$; that is, *the power is to the weight as the product of the arms (or acting distances) on the side of the weight, to the product of those on the side of the power.*

92. *Questions on the lever.*

1. The length of a straight lever is 25 inches, the weights on the ends are 15 lbs. and 60 lbs; when they balance, where is the fulcrum? *Ans.* 5 inches from 60 lbs.

2. The arms of a straight lever are 44 ft. and 5 ft.; if 500 lbs. are on the end of the short arm, what weight on the long arm would balance it? *Ans.* 56 lbs. 13 $\frac{1}{11}$ oz.

3. In a compound lever, the arms toward the power are 5, 10, 16 inches, and the others, 1, 2, 3 inches; if the weight is 100 lbs., what power will be in equilibrium with it?

Ans. 12 oz.

4. In a lever of the 3d order (Fig. 35), W is 5 lbs., and 8 ft. from F; with what force must I lift at P, 4 inches from F, to sustain W? *Ans.* 120 lbs.

5. In Fig. 36, if $P=40$ lbs., $p=12$ lbs., and $CM=9$ inches, how long is CN for equilibrium? *Ans.* 2 feet 6 inches.

93. *Weighing instruments.*—Most weighing instruments are constructed on the principle of the lever. In some, the weight is determined by the variations of the *poise* itself; in others, by the variations of the *acting distance* of the poise. An instru-

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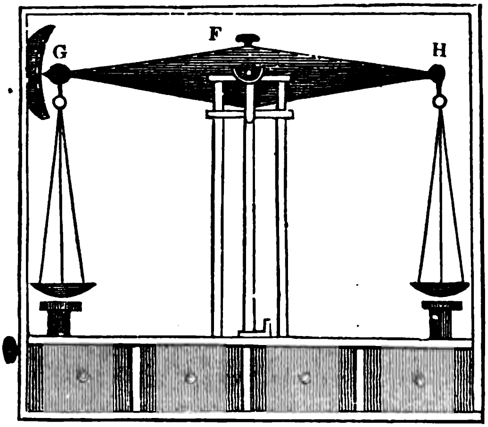
Prove and state the law of the compound lever. In what two ways is the weight determined by weighing instruments?

ment of the first kind is called the balance; one of the second kind, the steelyard.

In every weighing instrument, the center of gravity must be a little below the fulcrum, to secure a stable equilibrium, when the lever is horizontal.

94. In a *balance*, the arms are equal, and the scales hang from points which are in a straight line with the fulcrum. Hence, the substance weighed is equal to the poise; therefore we know the weight of the substance, by the poises which are placed in the opposite scale, to produce equilibrium. In the nicest kind of balance, used for scientific research, careful attention is given to the construction of all its parts. The arms are made light, and yet of such form as not to bend. The bearing points of the scales are precisely equidistant from the fulcrum, and in the same straight line with it. The knife-edges of the

Fig. 38.

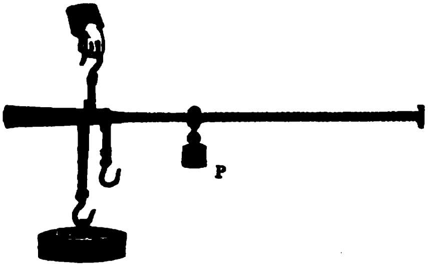


How is the center of gravity situated? Why? Describe the balance.

fulcrum are accurately formed, and but very little above the center of gravity, in order that the equilibrium may be delicate. Fig. 38 represents a balance used for chemical analysis. An index at G moves along a scale, to show the horizontal position of the beam. One-thousandth of a grain will in some balances give a sensible motion to the index.

95. In the *steelyard*, equilibrium is produced by changing, not the poise itself, but its acting distance. Thus (Fig. 39), if P, at a certain distance from the fulcrum, balances 1 lb. on the hook, at twice that distance it will have twice the *moment*, and will therefore balance 2 lbs.; at thrice the distance, 3 lbs., &c. The notches of the bar are marked by the number of pounds which the poise will balance. The steelyard usually has two fulcrums at different distances from the weight-hook, so that, by turning the bar over, and using the fulcrum nearest the weight, another set of notches, of higher number, may be used.

Fig. 39.



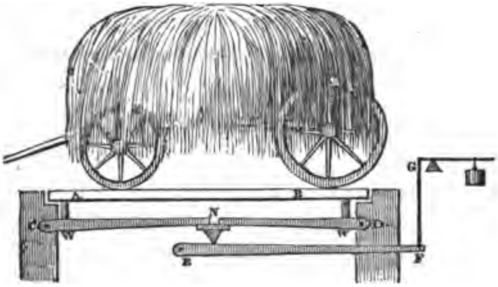
The steelyard is very convenient for ordinary uses, but is not easily made with sufficient accuracy for the nicer purposes of science.

96. *Platform scales* are constructed on the principle of a

How small a weight will turn the scale in a nice balance? How is equilibrium produced in the steelyard? Why has the steelyard two fulcrums?

compound lever. There are various contrivances for keeping the platform, on which the weight rests, firmly in a horizontal position, without destroying the delicacy of the equilibrium. Fig. 40 shows the plan sometimes adopted in the *weighing machines* for loads and heavy animals. The platform A B has attached to it, at its four corners, short pillars, which bear at W, W, on four levers, near their fulcrums, C, D. These levers are of the 2d order, and have their fulcrums at the corners of the cell beneath the platform, while their other extremities all reach nearly to the middle of the cell, and press on a common knife-edge at N, upon the lever E F, also of the 2d order. By the rod F G, this lever is connected with another, on which the poise is placed. The platform is in no danger of tipping, because it is supported at four points; and the four levers, C N, &c., being divided at W in the same ratio, act as one lever upon E F. Suppose the ratio of the arms of the lever G to be

Fig. 40.

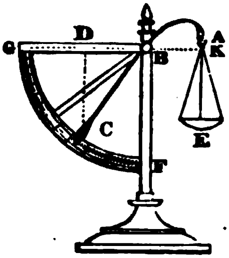


1 : 20;
of E F, 1 : 20;
and of C N, 1 : 15;
then the ratio of P to W is 1 : 6,000.

On what principle are platform scales constructed? How is the platform kept firm? Describe.

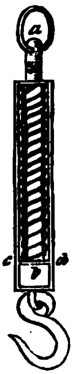
97. *The bent-lever balance* is represented in Fig. 41. The fulcrum is at B, and the arms, C B, B A, make an angle of 135° with each other, so that when B C is vertical, B A is 45° *above* a horizontal line, and when B C is horizontal, B A is 45° *below* horizontal. Hence, while the acting distance of the poise C, in moving from F to G, increases from zero to B G, the acting distance of the weight in the scale changes but little from B K, first increasing, then decreasing. The same poise C, therefore, can balance a variety of different weights, according to its height on the quadrant F G, on which these weights are marked.

Fig. 41.



Weighing instruments are sometimes constructed on other principles than that of the lever. For instance, the weight of a body may be measured by the effect it produces on an elastic metallic spring, as represented in Fig. 42.

Fig. 42.



98. *Implements, &c.*—No machine is so much used as the lever, in the common implements and contrivances for employing our strength to advantage. The crow-bar, used in prying, is a straight lever; the hammer, in drawing a nail, is a bent lever; shears, scissors, pliers, and nut-crackers, are double levers; the axe, shovel, hoe, &c., are examples of levers of mixed orders, where each hand is a fulcrum in part, and in part a power. The oar of a boat is of the 2d

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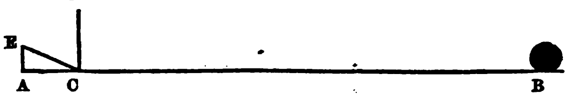
What angle do the arms of the bent-lever balance make with each other? How is the same poise made to balance many different weights? What other principle is sometimes used for weighing? Illustrate the lever by implements; bar; hammer; shears, &c.; axe, &c.; boat.

order, so far as it moves the boat forward; of the 1st order, so far as it throws the water back. A man, in handling a large box, and tipping it from one edge and angle to another, makes a lever of the weight itself; and we do the same in swinging a door upon its hinges. When a ladder is raised by revolving it upon its lower extremity, it is a lever of the 3d order; and here a laborer uses his strength to disadvantage; that is, he cannot raise *so great a weight* in this way, as by direct application without a lever; but he can move it more swiftly.

99. *The limbs of animals.*—These are levers of the 3d order. Each limb is moved by the contraction of a muscle, attached at a little distance from the joint, and giving motion to it through a strong cord. As an example, the fore-arm (that portion of the arm below the elbow) is lifted by a muscle lying on the front of the upper arm, from which a cord descends, and attaches to the bone of the fore-arm near the elbow, which forms the fulcrum. Since the power and weight have equal moments, the force exerted through the cord must be as many times greater than the weight in the hand, as it is nearer the elbow. And when the arm begins to move, it must be even much greater than this, on account of its oblique direction, as seen in Fig. 43. If A is the joint of the elbow, and the

Fig. 43.



cord is attached at C, then the power of the muscle is to the weight B in the hand, as A B to A C, provided the muscle acts

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What machine is a heavy box, when a man is tipping and turning it? What order is a long ladder when raised? Of what order are the limbs of animals? Describe how the arm is moved by the muscle.

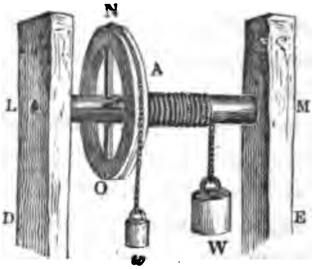
perpendicularly, in the line C D. But when the arm is nearly straight, the cord is very oblique, as C E; and the acting distance is the perpendicular from A upon C E; hence P is to W, as A B is to that perpendicular.

The advantages of the third kind of lever in the formation of limbs, are seen in the compactness of their structure, in the velocity communicated to them, in the protection of tendons within the flesh, and in the small extent through which the muscle needs to contract.

2.—THE WHEEL AND AXLE.

100. *The Wheel and Axle* consists of a cylinder and wheel, firmly united together, and free to revolve on a common axis. The power acts at the circumference of the wheel, and the weight in the opposite direction at the circumference of the cylinder or axle. Each radius, as it comes to the point where the force is applied, takes the place of an arm of a lever; the wheel and axle is therefore a sort of endless lever. In Fig. 44, where *w* on the wheel is a power in equilibrium with W on the axle, they have the same relation to each other as if on the ends of a lever of the first order, whose acting distances are equal to the radii respectively; therefore *w* (or P) : W : : rad. axle : rad. wheel; hence P × rad. wheel = W × rad. axle; or, *the moment of the power equals the moment of the weight.*

Fig. 44.

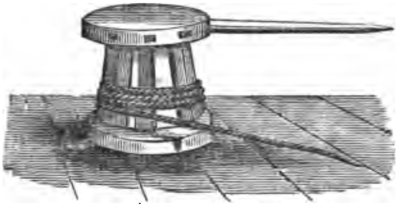


What force must be applied? What are the advantages of the third order? What does the *wheel and axle* consist of? What takes the place of the arms of a lever? What is the *law* of equilibrium? Give it in another form.

The *diameters* may be used instead of radii, in stating this law, since they have the same ratio to each other.

101. Instead of a wheel, one or more spokes of it may be used with the same effect; as the crank in a windlass, or the bars in a capstan (Fig. 45). In the latter, several bars can be inserted in the holes, and the whole strength of a man exerted at each one, for the purpose of raising an anchor, or other great weight.

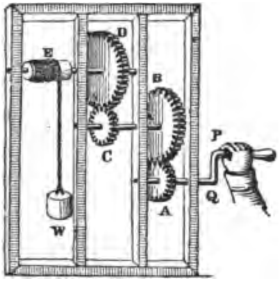
Fig. 45.



As in the lever, so in the wheel and axle, the power and weight are to each other inversely as their velocities.

102. *The compound wheel and axle.*—The wheel and axle is much more employed in the compound form, than the lever is. Fig. 46 illustrates the usual manner of doing it by toothed wheels. Those wheels in a machine, which communicate motion to others by the circumference, are called *driving wheels*, and those which receive motion by the circumference are called *driven wheels*. When the crank P Q is turned, it is seen that A and C are driving wheels, and B and D are driven

Fig. 46.



What may be substituted for the wheel? How is the wheel and axle compounded? What are *driving* wheels? *Driven* wheels? Give the ratio of power to weight.

wheels. The crank P Q must be reckoned among the driven wheels, and the axle E, among the driving wheels. The force which A exerts on B, call x; that which C exerts on D, call y; then, by the law of the wheel and axle,

$$P : x : : \text{rad. } A : P\,Q.$$
$$x : y : : \text{rad. } C : \text{rad. } B.$$
$$y : W : : \text{rad. } E : \text{rad. } D.$$

Multiply these proportions together, and divide by x and y, and we have

$$P : W : : \text{rad. } A \times \text{rad. } C \times \text{rad. } E : P\,Q \times \text{rad. } B \times \text{rad. } D;$$

or, *the power is to the weight as the product of the radii of the driving wheels is to the product of the radii of the driven wheels.*

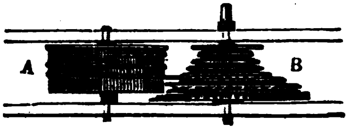
103. *Questions on the wheel and axle.*

1. The diameter of a wheel is $4\frac{1}{2}$ ft., and that of the axle $1\frac{1}{4}$ ft.; what power will be required to balance 100 lbs.? *Ans.* 27 lbs. $12\frac{4}{9}$ oz.

2. $P=12$ lbs., $W=100$ lbs.; diam. axle$=1$ ft.; required the diameter of the wheel. *Ans.* 8 ft. 4 in.

3. Three driving wheels of a machine are 8 inches in diameter, and the axle 6 inches; the driven wheels are respectively, 5 ft., 4 ft., 3 ft., 2 ft., in diameter; and the power is 10 lbs.; what weight would be in equilibrium with it? *Ans.* 8,100 lbs.

Fig. 47.



104. *The fusee.*—In some watches, there is a contrivance called the *fusee*, intended for equalizing the effect of the main-spring. When first wound up in the barrel A (Fig. 47), it draws most powerfully on the chain; and as it uncoils, its force becomes less and less. But the pressure produced by the teeth

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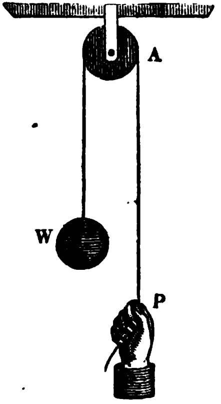
What is the purpose of the *fusee* in a watch? Explain its operation.

of the wheel B on the other wheels of the watch ought to be always the same. Hence the chain from A is wound off from a spiral groove on the axis of B, first from the smallest part of the spiral, and then from larger and larger parts, as the spring uncoils. Thus the *acting distance* becomes greater, as the force itself becomes less, so that the *moment* of the force is kept constant.

3.—THE PULLEY.

105. The *pulley* consists of a wheel or roller, with a cord passing over its edge; the axis of the roller is in a *block*, which may be fixed, or may move with the weight; and the pulley is accordingly called a *fixed pulley*, or a *movable pulley*. The pulley owes its efficiency as a machine to the principle, that *any strain or tension, which is applied to one end of a cord, is transmitted through its whole length, however much its direction is changed.* The ropes of a pulley are in every case supposed to be parallel.

Fig. 48.



106. *The fixed pulley.*—Fig. 48 represents this machine. Its only object is to change the *direction* of the motion, for the same power is required to raise the weight in this way, as to raise it without a machine. The force exerted at one end of the rope being transmitted to the other end, the weight must just equal that force in order to be in equilibrium with it. Therefore, P = W. It is used very advantageously in *raising* a weight by pulling *downward*, so that the weight of the per-

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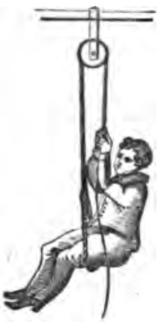
Describe the pulley. What two kinds? To what does the pulley owe its efficiency? State the use of the fixed pulley.

son shall aid his strength; and is for this reason of great service on shipboard. The *fire-escape* (Fig. 49) is sometimes nothing else than a fixed pulley attached near a window, by which a person with a rope, looped at one end, may let himself down, while one-half of his weight comes upon his hands.

Fig. 49.



107. *The movable pulley.*—In Fig. 50 the tension produced by P is transmitted from A down to E, and thence up to the beam; so that W is sustained by *two* portions of rope, each of which exerts a force equal to P; therefore W=2 P; or, P : W :: 1 : 2. So, in Fig. 51, P, on the end of the rope, transmits its tension to every part of it, and *six* portions are employed in sustaining W. Therefore P : W :: 1 : 6. In general, in all pulleys, where only one rope is used, *the power is to the weight, as* one *to the number of times the rope passes between the blocks.*

Fig. 50.

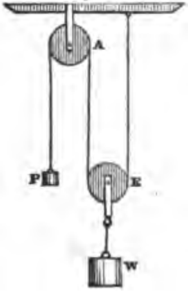
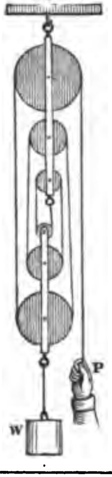


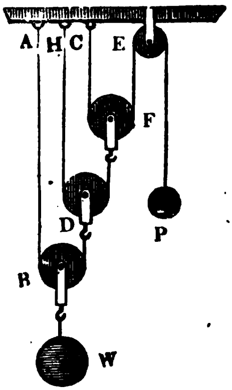
Fig 51.



108. *The compound pulley.*—If each movable pulley has its separate rope, the machine is *compound.* In Fig. 52, let the weight hanging on F be called *x*, and that on D, *y*.

Describe the fire-escape. What is the ratio of power to weight in the movable pulley? When is the pulley compound?

Fig. 52.



Then, as in Fig. 50,

$$P : x :: 1 : 2 ;$$
$$x : y :: 1 : 2 ;$$
$$y : W :: 1 : 2 ;$$

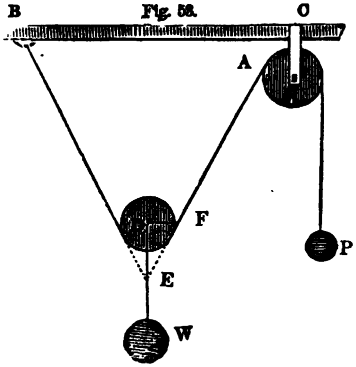
Therefore, $P : W :: 1 : 2^3 = 8$; or, *the power is to the weight, as* one *to that power of* two *expressed by the number of ropes.*

109. The pulley is efficient as a machine, because the tension exerted by the power at one end of a rope, is applied repeatedly to the weight. The wheel serves no other purpose than to diminish friction. Were it not for friction, the rope might just as well pass around fixed pins in the blocks.

4.—THE ROPE MACHINE.

110. When the ropes of a pulley are not parallel, the instrument receives the name of the *rope machine;* and the laws which have been stated are not applicable. If, in Fig. 53, the parts of the rope, by which D is upheld, are oblique to each other, W cannot be so great as *twice* P, as it is, when the ropes are parallel (Art. 107). For, let E F represent the tension of P,

Fig. 53.



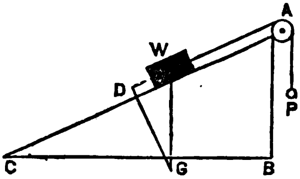
State the law of equilibrium. Of what use is the wheel in the pulley? When does the pulley become a rope machine?

and resolve it into E D and D F. E D is the only component employed in supporting W; but as the tension on the other side is equal to E F, there is another upward force, found by resolving that: so that the whole force which directly supports W, is *twice* E D; and therefore P : W : : E F : 2 E D. Since E D is always less than E F, W is less than twice P. As D is raised higher, E D diminishes, and therefore the weight sustained becomes less and less.

5.—THE INCLINED PLANE.

111. It requires less force to move a body up an inclined plane than to raise it perpendicularly, because the plane itself partly supports the weight. This appears by resolving the force of gravity. Suppose W to be prevented from descending the plane A C (Fig. 54) by P, acting by a cord over the fixed pulley A. Let the weight W be represented by W G, drawn in the direction of gravity, and resolve it into W D, parallel to the plane, and D G, perpendicular to it. D G is neutralized by the reaction of the plane; so that, if the power acts up the plane with a force equal to D W, the weight will be in equilibrium. Therefore, P : W : : D W : W G. And, as W D G and A B C are similar triangles, P : W : : A B : A C; that is, *the power is to the weight, as the height of the plane is to its length.*

Fig. 54.



112. This is the law of equilibrium when the power acts parallel to the plane; and this is the usual direction, because

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Show that the weight cannot equal twice the power. Why does a less force sustain a weight on an *inclined plane* than directly? Show the ratio of power to weight, by resolving. State the *law* of the inclined plane.

it is more efficient than in any other. If the power acts parallel to the *base* of the plane, it could be shown in a similar manner, that P : W : : A B : B C; or, height : base.

113. It is clear from the demonstration, that the more nearly horizontal a plane is, the greater is that component of the weight which is neutralized by the plane, and the less is that which the power has to overcome. It would appear, therefore, that on a *horizontal* plane, *no* force is needed. This is obviously true, for a weight at rest on a level surface is in equilibrium, without the application of any force. And if in motion, it would by its inertia continue in motion, were it not for obstructions.

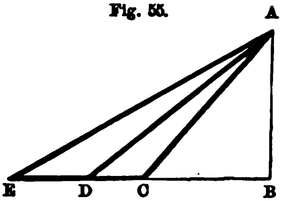
114. *Roads.*—When roads are not perfectly level, they are examples of the inclined plane; and while one part of an animal's strength is needed for overcoming friction, just as on level roads, another part is always necessary for *lifting* a certain fraction of the weight. Thus, if a road rises *one* foot in 100 ft., then, since P : W : : height : length, a horse, in drawing up a load, has to lay out strength enough to lift $\frac{1}{100}$ of the load, besides what is expended in overcoming friction.

115. *Descent on an inclined plane.*—The tendency of a weight down a plane is clearly equal to the power needed to prevent its motion. Hence, the force which urges a body down a plane is to the whole force of gravity, as the height is to the length. On a railroad, which rises *one* foot in 300 ft., a train tends to go down with a constant force equal to $\frac{1}{300}$ of its weight. The motion down a plane is, therefore, *uniformly accel-*

In what direction is the power supposed to act? If the power acts parallel to the *base*, what is the law? What is the effect of diminishing the inclination? Suppose the plane horizontal. On an inclined road, what part of the weight must the horse *lift?* Illustrate by numbers. How great is the tendency of a body down a plane? Example.

erated, though at a less rate than in falling perpendicularly. And, if a body is projected up a plane, its motion is *uniformly retarded*, because a *constant* force (though less than the force of gravity) is operating to hinder its motion.

Fig. 55.

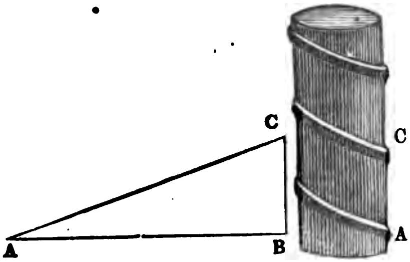


116. If different planes, as in Fig. 55, have the same height, it is proved that the *time* of descent will be as much greater as the plane is longer; but the *velocity* acquired will be exactly the same, whether down A D, A E, A C, or perpendicularly down A B.

6.—THE SCREW.

117. If a piece of paper be cut in the form of a right-angled triangle, Fig. 56, and then wrapped round a cylinder, whose circumference is equal to the base of the triangle, the inclined plane, represented by A C, will become a spiral line, and the height of the triangle will be the distance between two successive revolutions. The machine known as *the screw*, consists of a cylinder with a groove cut around it in this form, while a concave cylinder, called the *nut*, having a

Fig. 56.

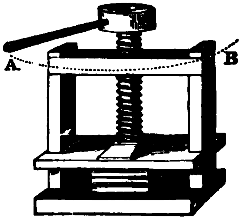


What kind of motion has a body in going *down* a plane? *Up* a plane? Descent on planes of different length, but of the same height, how are the *times?* How are the velocities? Show that a *screw* is the same as an inclined plane.

similar groove, fits upon it. If the nut is free to move only vertically, and the screw be turned round horizontally, by a force applied at the surface, the case is analogous to raising a weight on a plane by a force parallel to the base of the plane. But, in the plane (Art. 111), P : W : : height : base. Therefore, in the screw, the power is to the weight as the distance between the threads is to the circumference of the screw.

118. The screw is generally turned by using a lever or bar, inserted in the cylinder, as in Fig. 57. In this case, the power gains efficiency just in proportion as the circumference is increased; so that the law of the screw, in general, is this: *the power is to the weight as the distance between the threads is to the circumference described by the power.*

Fig. 57.



119. The circumference described by the power may easily be made very great, compared with the distance between the threads; and therefore the intensity of force produced by the machine may be equally great compared with the power. And since the bar may be inserted when the force is to be applied, and afterwards removed, the machine is very compact as well as efficient. Hence it is much used for presses, and wherever intense force is to be exerted through small spaces, as in lifting buildings up from their foundations.

120. *The endless screw.*—Not only is the screw ordinarily compounded with the lever, as just stated, but sometimes its

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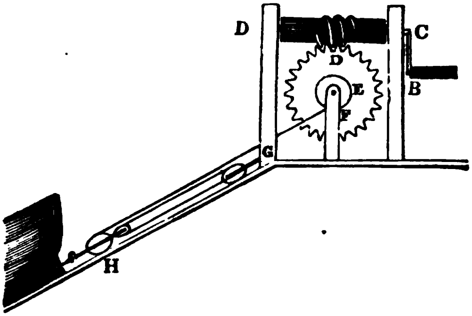
What does the height become? What the base? Give the *law* of the screw. How is the intensity of the effect made very great? For what purposes is the screw used? When called an *endless* screw?

thread works in the teeth of a wheel, as represented in Fig. 58. In this case, the lever and screw form a compound machine with the wheel and axle. This figure represents the pulley and inclined plane as also combined with the others.

Fig. 58.



Suppose the radius B C=18 inches; distance between threads =1 in.; diam. of wheel E D=4 ft.; do. of axle=1 ft.; the pulley G H, with one rope passing four times between the blocks; the height of the plane=half its length; to find the weight sustained on the plane by 100 lbs. at B.

In screw and handle (Art. 118), P : W : : 1 : 36 × 3.14159,
or, P : W : : 1 : 113.0972.
In wheel and axle (Art. 100), : : 1 : 4
" pulley (Art. 108), : : 1 : 4
" inclined plane (Art. 111), : : 1 : 2

And 100 lbs. : weight : : 1 : 3619.11
Hence the weight=100 × 3619.11=361,911 lbs.

What are the several simple machines in Fig. 58?

7.—THE WEDGE.

121. We have seen that on an inclined plane, when the power acts parallel to the base, P : W : : height : base. On account of equal action and reaction, the same would be true, if the plane itself were moved horizontally, while the weight resting on it was confined to move vertically. The plane thus used becomes a *wedge;* hence, in the wedge, *the power is to the weight as the back of the wedge is to its length.* If the pressure which is produced on *both* sides of the wedge is included in the *weight,* as it often is, then the law of equilibrium would be, the power is to the weight as *half* the back of the wedge is to the length. It is obvious from the law, that the less the angle of the wedge, the greater is its efficiency. But the angle must not be too small, lest the wedge lose its strength; and the proper size of the angle depends on the hardness of the material to be divided. Wedges are used where great pressures are to be exerted through a small space, as in splitting timber or stone. The force is generally applied by a series of *blows,* the friction holding the wedge in place during the interval between them. Some cutting tools act on the principle of the wedge entirely, as the axe, and the chisel when driven by a mallet; but more frequently cutting tools derive a part of their efficiency from the oblique or lateral motion, which is given to them in addition to the pressure. This is seen in *drawing along* a knife, as it is *pressed* down. The effect of the lateral motion is supposed to be due, at least in part, to the *roughness* of the edge, acting like the teeth of a saw.

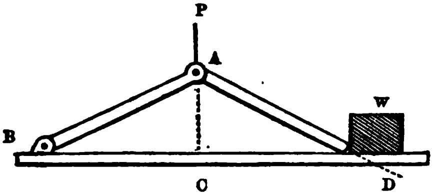
How does the inclined plane become a *wedge?* State the *law* of the wedge. How is its efficiency increased? When are wedges used? How is the force commonly applied? Do all cutting instruments operate wholly on the principle of the wedge? How does this appear?

8.—THE KNEE-JOINT.

122. This is a machine consisting of two bars, usually equal, hinged together at one end, while the others can separate in a straight line. The power is applied to the hinge, tending to thrust the bars into a straight line; and the *weight* is the resistance to be overcome by the moving extremity.

123. In Fig. 59, let the power P act in the direction A C, perpendicular to B D, while the end B of one bar turns on a pivot, and the other, D, encounters the resistance W. The power exerts equal pressures along the bars. Let A B represent one of these forces, and A D the other. Resolve A B into A C and C B; and A D into A C and C D. Then the whole downward force, 2 A C, is counteracted by the plane B D; the horizontal force C B is counteracted by the pivot B; and the other, C D, is exerted in overcoming W. If now W is represented by C D, there will be equilibrium, when the whole force P is represented by 2 A C. Therefore,

Fig. 59.



P : W : : 2 A C : C D; or, *the power is to the weight as twice the distance from the joint to the line between the ends of the bars, is to half that line.*

Describe the *knee-joint*. Prove by the figure what is the ratio of P to W. State the result as a *law* of the knee-joint. As the joint is depressed, what change in this ratio?

124. As the joint approaches the line, the power grows more and more efficient, because A C becomes smaller, and C D larger. For example, if A D=10 in., and A C=8 in., then C D=6 in., and P : W : : 2×8 : 6, or as 8 : 3; when A C=6 in., then C D=8 in.; and P : W : : 3 : 2; and when A C=$\frac{1}{2}$ in., C D=9.99 in.; and P : W : : 1 : 9.99. In the first position, the weight equals only $\frac{3}{8}$ of the power; in the second, it equals $\frac{2}{3}$ of it; and in the third, it is about *ten* times as great as the power. It is this peculiarity in the knee-joint,—namely, the increasing efficiency of the power as the bars approach a straight line,—which gives to this machine its principal value. It is extensively used in printing, coining, and similar operations.

While W itself becomes greater, it is evident that its velocity becomes less, as in all other machines.

CHAPTER VI.

MACHINERY.

125. It was stated (Art. 86), that machines are not designed for producing effects which are *greater* than what the power alone could produce without their aid, but for *varying* the *character* of these effects. That the effect is not greater than the cause, appears from the fact noticed in all the simple machines, and which has been repeatedly mentioned, that according as the

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Illustrate. The value of this machine. Where used? How does it appear that a machine does not increase power? What is its use? What modifications are first mentioned?

weight is greater, its velocity is less; so that the momentum remains the same.

126. *Variations in velocity and intensity.*—The purpose of the machine sometimes is to move a *great mass*, or to exert *intense pressure;* as, when a man by his strength raises a large rock with a lever, or a corner of a building with a screw, or cuts a sheet of iron with shears; but in all such cases, while the *intensity* of the effect is increased, the *velocity* is diminished. The whole effect, properly measured, is not greater than the power. In other cases, the machine is designed to produce *great velocity;* as when a person whirls the article which he is turning in a lathe, by the strength of his foot on the treadle. Here, the *speed* is great, but the intensity of the force is small, so that the total effect is no greater than that which the same strength could have produced without the machine.

127. *Wheel-work.*—In machinery, great use is made of wheels, for varying the velocity or intensity, while communicating motion from one axis to another. The connection of wheels by teeth is called *gearing;* small toothed wheels are often called *pinions*, and their teeth *leaves.*

128. If two wheels are on the same axis, the velocities of the circumferences are proportional to the number of teeth. But when one wheel gears into another, the absolute velocities of the circumferences must of course be the same; and therefore the smaller will make as many more revolutions than the larger, as its number of teeth is less. Thus (Fig. 60), the wheel A, having twelve teeth, and the pinion B, having five leaves, B will revolve 2⅖ times, while A revolves once. If now a wheel

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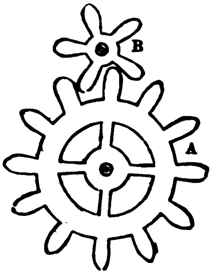
Mention cases where great *intensity* is needed. A case where great *velocity* is desired. What common way of changing velocity? State velocities when two wheels are on the same axis. When one wheel turns another by *teeth*. Illustrate both by an example.

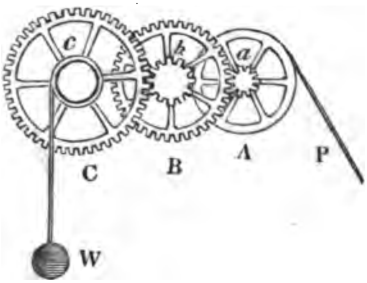
Fig. 60.



of 100 teeth is confined to the axis B, it will make the same number of revolutions as B, but its circumference will move 20 times as fast. If, again, the teeth of this wheel drive another pinion of five leaves, this last will revolve 20 times while B revolves once, and 20 × 2⅖ (=48) times during one revolution of A. Thus, the speed of revolution from axis to axis can be increased or diminished at pleasure.

129. In Fig. 61, if the wheels B and C have 100 teeth each, and the pinions *a* and *b* ten leaves each, then the axis of *a* revolves 100 times, while that of *c* revolves once. If, moreover, the radius of the wheel A is three times that of the axle *c*, the velocity of P is 300 times that of W. And since the velocities are inversely as the forces (Art. 101), the force applied to the wheel A is only $\frac{1}{300}$ of W, in order to be in equilibrium with it.

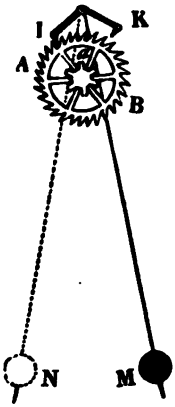
Fig. 61.



It is obvious that two successive axes must revolve in contrary directions; if, therefore, it is desired to have two axes move in the same direction, there must be an intervening wheel to produce the change.

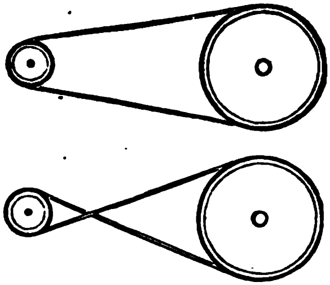
Show the ratio of power to weight by an example. In what direction do two successive wheels revolve? How can one wheel cause another to revolve in the *same* direction?

Fig. 62.



130. In a clock, the train of wheels is intended to convey from the weight a gentle but long-continued pressure to the pendulum. The scape-wheel A B (Fig. 62) is the last of the series; at each swing of the pendulum, a tooth escapes from the pallet I or K, and in doing so exerts a slight pressure, which prevents the pendulum from losing any in the extent of its oscillation. As there are many thousands of beats every day, the velocity of the scape-wheel needs to be much greater than that of the cylinder on which the weight hangs. Hence, the necessity of many wheels, in order that frequent winding may be avoided.

Fig. 63.



131. *Bands* are used in transmitting rotation from one axis to another when they are *distant*, and when a precise ratio of velocities is not essential. The ratio is estimated in the same way as in *toothed* wheels, but it is liable to change by the slipping of the bands. It is readily seen (Fig. 63), that the small wheel revolves as many more times than the large one, as it is smaller in circumference, or

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Why are so many wheels put into a clock? What effect does the *weight* produce? Explain the operation of the scape-wheel. How is frequent winding avoided? How is rotation communicated between *distant* axles? How is the ratio of velocity estimated? What objection to bands?

diameter, provided the band does not slip on either wheel. The two will revolve in the same direction when the band is not crossed, and in contrary directions when it is crossed.

132. *Change of direction in axes.*—The teeth of wheels are usually cut on a cylindric surface, as in Fig. 64, for communicating motion between *parallel* axes. Such wheel-work is called *spur gearing.* But if axes are oblique to each other, rotation is communicated by teeth cut on a *conical* surface, as represented in Fig. 65. This is called *bevel gearing.*

Fig. 64.

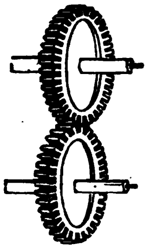


Fig. 65.

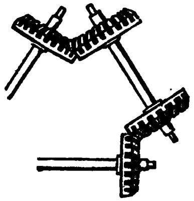
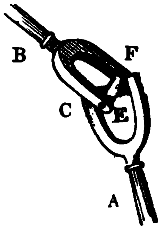
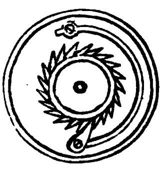


Fig. 66.



There are also contrivances for allowing an axis to change its direction from one position to another, even while it is revolving. . Fig. 66 presents an instance, called the *universal joint.* Each axis terminates in a semicircular fork; and these are hinged to an intermediate piece by two axes at right angles to each other.

Fig. 67.



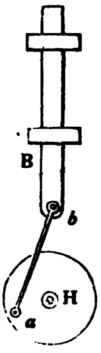
A *ratchet* (Fig. 67) has oblique teeth, and a catch falling between them by a spring, so as to allow free revolution one way, and no motion in the opposite.

What is the effect of *crossing* the bands? Describe *spur* gearing. *Bevel* gearing. When is the latter used? State the use and construction of the *universal joint.* What modification is caused by the ratchet?

133. *Variations in the line of motion.*—All the machines described in the foregoing chapter may cause variations in the *direction*, and also in the *character* of the line in which the motion occurs. Thus, in the first order of lever, when the power *descends*, the weight *ascends*; the same is true of the wheel and axle, and of the pulley generally. Again, the power may move in the *circumference* of a circle, and the weight in a *straight line*; as in raising a bucket by a crank, and in pressing substances by a screw. Or the reverse of this may be true, as in a clock, where the moving force (the clock-weight) describes a straight line, but the scape-wheel (whose pressure on the pallets of the pendulum is the effect produced) revolves in a circle.

134. Besides these variations in the line of motion, there is another of very frequent occurrence; the power may have a constantly *progressive* motion, and the weight an oscillating motion, or the reverse. The water-wheel revolves continually in one direction, but the saw which is driven by it vibrates up and down. But in the turning-lathe the reverse takes place; the treadle vibrates, and the article turned revolves constantly in one direction. The *crank* (Fig. 68) is a familiar contrivance used for producing both these changes. If the wheel H revolves, it causes the rod B to move alternately up and down within the guides, by means of the crank-rod *a b*; or, on the other hand, if B oscillates, it communicates a revolving motion

Fig. 68.



What other changes beside that of velocity do machines produce? Illustrate by *lever*, *wheel and axle*, and *pulley*. Also by bucket raised by crank, and the scape-wheel of a clock. What other change still? Give example in the saw. Also in the lathe. Use of the *crank*?

to H. A very common element in machinery for producing oscillating motion is the *cam*, which is simply a projection on one side of an axis. As the axis revolves, any thing which rests against the cam moves to and fro alternately at every revolution. A series of strong cams on the circumference of a wheel gives to the trip-hammer its rapid and powerful action. The cam, in the form of a circle, placed eccentrically on an axis, and hence called an *eccentric*, is used much in steam machinery for opening and shutting valves.

135. *Regulators of machinery.*—Machinery is usually subject to changes in velocity. These changes arise sometimes from changes in the prime mover, as when the force of steam is greater or less, according to the fire; and sometimes from changes in the resistance to be overcome, as when, in a weaving-room, a part of the looms are stopped, and again set going. In such cases injury is likely to be done, both to the machines and to the manufactured articles, unless some means are used either to prevent changes of velocity altogether, or else to render them gradual.

136. *The governor.*—This regulator is intended to keep the velocity of the machinery *uniform.* It consists of two heavy balls, C C′ (Fig. 69), on the ends of two bent rods, C B D, C′ B D′, which are hinged to an upright axis A E. This axis, with its rods and balls, is continually whirling, when the machinery is in motion. The centrifugal force tends to throw the balls out from the arms, against which they would rest if the machinery were stopped; and, at the proper velocity, they maintain a certain distance from the axis, which is not altered so long as the

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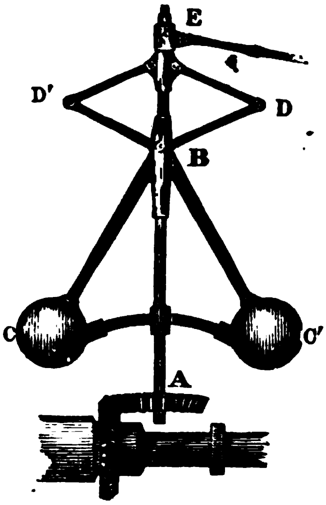
What is a *cam*, and what is its use? Examples. Why are regulators needed in machinery? Describe the *governor*. On what does it operate? If the machinery is moving too slowly, what effect is produced?

Fig. [illegible].



velocity is not changed. But if the power is increased, or if some of the machinery is ungeared, the velocity would increase, the balls would spread out a little farther, and in so doing would draw down the end of a lever, E, and partly shut the valve which admits water or steam; thus the velocity is instantly reduced to its proper rate. On the other hand, suppose the power to grow more feeble, or more than the usual machinery to be attached, then the velocity is too small; and the balls, losing a part of their centrifugal force, descend toward the axis, press up the end E of the lever, and thus open the valve for the water or steam to enter at a faster rate, and restore the velocity.

137. *The fly-wheel or balance-wheel.*—This kind of regulator is not intended to keep the velocity uniform, but only to prevent *sudden changes*, when the power or the resistances are suddenly altered. It is simply a large wheel with a heavy rim (Fig. 70), which revolves at a certain rate, according to the velocity of the machinery at the time. If the power diminishes, or the resistance increases so as to reduce the speed, this heavy

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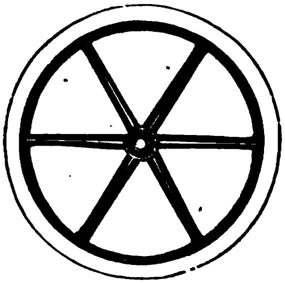
If too swiftly, what effect? Does the *fly-wheel* keep the motion uniform? Describe it, and the effect it produces when the power diminishes. When it suddenly increases.

Fig. 72.



wheel, by its *inertia*, tends to keep on at its former rate, and loses its velocity only very gradually, and thus prevents a sudden diminution of velocity in the other parts of the machinery. And, in a similar manner, if the power becomes more energetic, or if some of the machines are ungeared, the others will not be suddenly driven with a great velocity, because the inertia of the fly-wheel is so great that it gains velocity only very slowly. Thus it allows changes, but renders them all very gradual.

138. *Friction.*—The laws of simple machines, given in Chapter V., are true only on the supposition of perfectly unobstructed motion, in obedience to the forces considered, which are called the *power* and *weight.* After determining these laws by calculation, suitable allowance must be made for *obstructions* to motion, which always exist in some degree. The principal obstruction is *friction.* This arises from roughness, and is diminished by rendering surfaces more smooth. But as the microscope shows that a surface is never absolutely smooth, so the most perfect machine proves that there always is some degree of friction.

139. The amount of friction in a machine depends on the *kind* of machine, on the *material* of which it is made, and on the *care* which is employed in its construction. But, in ordi-

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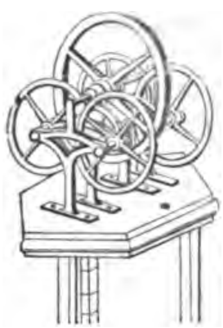
Are the laws of machines given in Chapter V. *practically* true? Why? State the *cause* of friction. What does its amount depend on? In what case is friction greatest?

nary machines, *one-fourth*, or even *one-third* of the calculated effect must be deducted for this and other obstructions.

140. The friction which occurs when one surface *slides* on another, is greater than when it *rolls*. Hence the use of wheels in vehicles. Sometimes *friction-wheels* are introduced into machines, for the purpose of reducing the friction in the greatest possible degree. Fig. 71 shows the wheel of Atwood's machine mounted on friction wheels. If the axis of the principal wheel rested in sockets, the surfaces would *slide*, but by letting it rest on the circumferences of four other wheels, as represented, it *rolls* on them, causing them to revolve slowly. There is, however, sliding friction between the axes of these other wheels and the sockets in which they revolve, but it presents much less obstruction, because overcome on the principle of the wheel and axle.

Fig. 71.



141. Though friction is apt to be considered an evil, since more power is required to produce given effects than if friction did not exist, yet, on the whole, it must be regarded as of incalculable advantage. Objects stand firmly in their places by friction; and the heavier they are, the more firmly they stand, because friction is increased by pressure. All fastening by nails and screws is due to friction. The fibres of cotton, wool, or silk, when intertwined with each other, hold together firmly in cloth, by the same force. Without friction it would be impossible to walk, or even to stand, or to hold any thing by grasping it with the hand.

Why are wheels used for vehicles? Describe *friction*-wheels. Is friction an evil? Illustrate its advantages by examples.

PART II.—HYDROSTATICS.

142. *Definitions.*—A *fluid* is a substance whose particles are easily moved among each other. The name *fluid* includes every thing which is not *solid.* It might appear as if the definition would apply to a solid when finely pulverized, but it does not; for each one of the *grains* of a pulverized substance is itself a solid, whose parts are not free to move among each other. Moreover, gravity will bring the surface of a fluid to a level, but not that of a powdered solid, because the particles are not all free to move. Fluids are of two kinds, *liquids* and *gases.*

A *liquid* is not compressed or expanded by force applied to it, except in a slight degree.

A *gas* can be compressed or dilated with ease, and beyond any know limits. *Water* is the common example of liquids, and *air* of gases.

143. It was for a long time supposed that water is wholly incompressible. But careful experiments have proved that it can be compressed slightly. An instrument, invented by Oersted, renders the compression produced by the weight of the atmosphere (which is a force of about fifteen pounds on a square inch), distinctly visible to the naked eye. He makes the compression of water equal to forty-six *one-millionths* of its

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Define a *fluid*. Does the definition apply to a pulverized solid? Why not? What two classes of fluids? Define each. Give an example of each. Is water compressible? How much by one atmosphere? How may liquids and gases be properly distinguished?

volume for one atmosphere. Still, for all the purposes of experiment or calculation, liquids may be regarded as *incompressible fluids;* and the gases, in distinction from them, may be called *compressible fluids.*

144. The mechanics of liquids is divided into two branches: the first treating of liquids at rest, properly called *Hydrostatics;* the second, of liquids in motion, called *Hydraulics.* The word Hydrostatics, however, is commonly applied to the general science of liquids, including both of these branches.

CHAPTER I.

LIQUIDS AT REST.

145. *Transmitted pressure.*—When a force is applied to any part of a fluid, it is transmitted undivided to every part of it. Thus, if the bung, occupying one square inch of the surface of a cask full of water, be pressed with a force of 50 lbs., then every square inch of the interior of the cask will receive a pressure of 50 lbs. And if the force is increased till the cask burst, it will give way in the weakest part, no matter whether in the direction of the pressure or not. A downward force not only produces *downward* pressures on the bottom, but *lateral* pressures on the sides, and *upward* pressures on the top, and pressures in all possible directions, according to the position of the surface. The bladder B, in the vessel of water A (Fig. 72),

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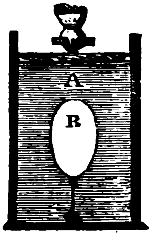
The mechanics of liquids is how divided? State the law of transmitted pressure. Illustrate by an example. Example of the bladder.

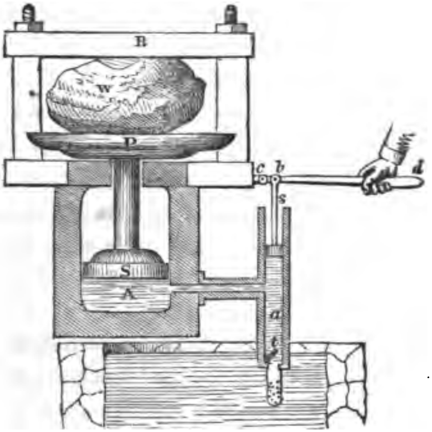
shows pressure on all sides, when the piston at the top is crowded down.

Fig. 72.



146. *The hydraulic press.*—The principle just stated explains the power of the hydraulic press (Fig. 73). In the tube of a small forcing pump *a*, a solid piston is moved by the rod and lever *s*, *c d;* water is thus brought up from the reservoir below, and driven into the large cylinder A, in which the piston S moves and acts upon the press above.

Fig. 73.



Whatever force is applied to the small piston, is repeated as many times on the large piston as the area of the latter is greater than that of the former. The principle of the *lever*

Describe the hydraulic press. How many times is the force of the small piston multiplied on the large one? What machine is usually combined with the power of the water?

is combined with that of transmitted pressure, so as to render the machine very powerful.

Suppose the arms $cb : cd :: 1 : 20$,
and the areas of the pistons as $1 : 144$, then

$P : W :: 1 : 2880$; therefore, a man by exerting a force on the lever of 50 lbs., will produce a pressure on W of 144,000 lbs.

147. Since the same quantity of water which is driven from the small cylinder is admitted to the large one, the piston S will move as many times slower than the other, as its area is greater. Hence, the same principle applies here as in other machines, that the *velocities* of power and weight vary inversely as their intensities.

148. This machine has an advantage over all others, in being remarkably free from friction. It is employed for pressing hay, cotton, paper, books, &c.; for uprooting trees, and testing the strength of ropes, chains, and building materials. The tubular bridge over the Menai Straits, after being constructed at the water level, was raised more than 100 feet, to the top of the piers, by two hydraulic presses. The weight of each portion lifted at once was more than 1,800 tons.

149. *Level surface.*—When a fluid is at rest, its surface is *level*, that is, it is perpendicular to the direction of gravity, as shown by a plumb-line. This is a consequence of the free motion of the particles; for if any portion of the surface is inclined, the particles will slide down by the force of gravity, till the whole surface is level.

150. A level surface is not a plane, but has the curvature

State the ratio of velocity in the two cylinders. What peculiar advantage has this machine? Its uses? What surface has a fluid at rest? Why? What *is* a level surface?

of the earth. If a straight line were to be drawn touching the ocean when at rest, the water, at the distance of *one* mile from the point of contact, would be about 8 inches below the line; at *two* miles, *four* times 8 in. = 32 in.; at *three* miles, *nine* times 8 in. = 72 in., &c.; the depression varying as the *square* of the distance. On a larger planet, it is obvious the depression would be less, and on a smaller planet, it would be greater.

151. *Leveling instruments.*—There are many ways of determining when a line is level; but the most convenient and accurate methods depend on the tendency of a liquid to rest only when its surface is level. Thus (Fig. 74), the line joining the two distant points P and Q, is considered to be level when it is found to be in the line with the surface of water in the tube A B, or parallel to it. This is determined by taking sight along A B. The spirit level is more delicate, and is therefore used for the nicest astronomical measurements. A small tube of glass, nearly filled with colored alcohol, is set in a metallic frame (Fig. 75). The tube is slightly convex upward, and is so adjusted that the fram

Fig. 74.

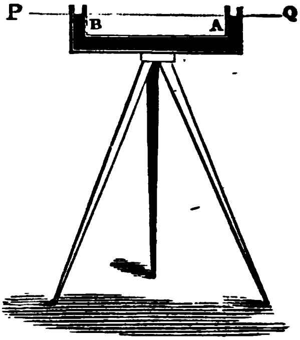
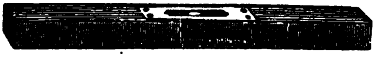
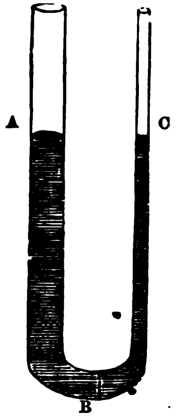


Fig. 75.



How much depressed from a plane in *one* mile? Two? Three? Give the law. How is a level determined? On what principle are leveling instruments generally made? Describe one kind. A nicer kind.

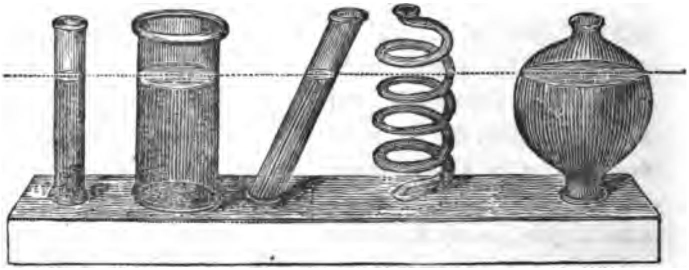
Fig. 76.



level when the bubble of air in the tube is at the middle of the length. A graduation on the tube shows minute deviations, and aids in approaching the true level.

152. All parts of the surface of water at rest are level, when the surface is interrupted as well as when continuous. Thus, in the recurved tube, A B C (Fig. 76), A and C are on the same level, however far apart the branches may be, and however unequal in size. If any number of tubes and vessels be connected together, as in Fig. 77, and water be poured into one of them, it will rise in all, so as to keep the surface level.

Fig. 77.



153. *Pressure as depth.*—If a liquid is of uniform density, the *pressure* on any surface within it *varies as the perpendicular depth*, whatever the form or size of the reservoir. In Fig. 78 the pressure on P P is equal to the weight of the column of water G P, which rests upon that surface. If anywhere on

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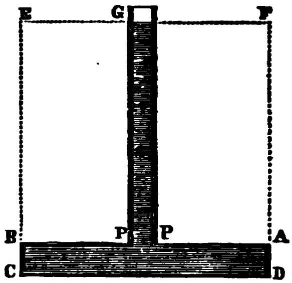
Water in a recurved tube. In a vessel with many branches. How does pressure vary? Does the *quantity* of water affect this law?

Fig. 78.

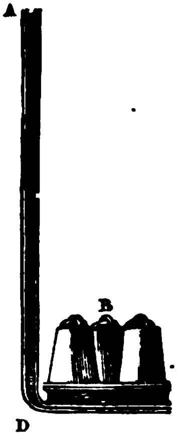


A P a space equal to P P be opened and a tube attached, water will stand in this tube as high as G (Art. 152); therefore there is everywhere on the level A B. a pressure as great as at P P, or the water in the supposed tube would not be sustained. It follows, that on every part of C D there is a downward pressure equal to that directly beneath the column G P. Thus it appears that the amount of pressure on a given surface is not determined by the quantity of water in the vessel, but only by the height to which the water extends. By making the lower part of the reservoir A B C D very shallow, and the tube G P very small, the pressure on the base might be hundreds or thousands of times greater than the weight of all the water in the vessel, because the pressure is the same as if the sides were raised to E F, and the whole reservoir, E C D F, filled to the height of G.

154. A cask, when filled with water, might be burst by an additional pint of water, or less; for, by screwing a long slender pipe into the top of the cask, and filling it with water, the pressure is easily made greater than the strength of the cask can bear. By the *hydrostatic bellows* (Fig. 79), we can measure the great pressures produced by a small quantity of water; as we have only to notice the number of pounds set upon the bellows to maintain the column A D. The proposition, that *a small quan-*

Show that this law is true. How may a small quantity of water produce great pressure? How can a *pint* of water burst a cask? How is the pressure measured?

Fig. 78.



tity of water may balance ever so great a weight, is often called the *hydrostatic paradox;* but it is no more paradoxical, than the statement that by means of a lever, or any other machine, a small weight may balance one ever so large.

155. Engineers find that a dam or bank, to sustain a narrow channel of water, must be built as strong as if to bear the pressure of a pond or lake of the same depth; and that aqueduct pipes must have increased strength, as they descend to greater depths from the source.

156. *Estimation of pressures.*—One cubic foot of water weighs 1,000 ounces, or 62½ pounds. Therefore, the pressure on *one square foot*, at the depth of *one foot*, is 62½ pounds. And since the pressure varies as the depth, we may hence determine the pressure on one square foot at any depth, by multiplying the depth in feet by 62.5. And, to find the pressure on any other area, multiply 62.5 by the depth, and that product by the area. If the area is not horizontal, use the average depth. At the depth of *five miles* the pressure on a square foot equals $5 \times 5280 \times 62.5 =$ 1,650,000 pounds. It is even *greater* than this, first, because salt water is heavier than fresh water; secondly, because water is compressible, and therefore a little more dense as the depth increases. A cubic foot of sea-water weighs 64.37 pounds.

157. *Loss of weight in water.*—When a body is immersed

The *hydrostatic paradox*, what is said of it? What strength is required to sustain the wall of a narrow channel full of water? The weight of one cubic foot of water? What surface at what depth sustains it? Show how to calculate pressure in all cases. Pressure in salt water compared with fresh.

in water, the lateral pressures balance each other, because the sides are at the *same* depth; but the downward pressure cannot balance the upward, because exerted at *different* depths. It is the excess of upward above downward pressure which constitutes the *buoyant power* of a fluid.

158. *The loss of weight* of an immersed body equals the *weight of displaced water.* For, before the body was immersed, the water occupying the same space was exactly supported by the excess of upward over the downward pressure. And after the body is immersed, the same difference of pressures must support so much of its weight as is equal to the weight of water displaced.

159. *Equilibrium of floating bodies.*—A body of the same density as water, remains wherever it is placed beneath the surface, because the loss just equals its whole weight. But if it is less dense than water, the loss exceeds its weight, and it is pressed partly above the surface, and there floats. A *body floats, when it is sunk deep enough to displace its own weight of water.* For the water, before being displaced, was just supported by the upward pressure beneath it; and the same pressure is now able to support a body of equal weight.

160. That a floating body may have a stable equilibrium, *the center of gravity of the body must be in the lowest possible situation compared with the center of the displaced water, and in the same vertical line with it.* Thus, a plank will not float on end, or on its edge, but on its side, because in the last position its center of gravity is lower, compared with the center of dis-

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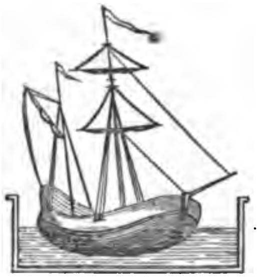
How is the weight of an immersed body affected? Why? What causes buoyant power in a fluid? How much weight does a body lose in water? Why? If a body just as dense as water is immersed, how will it move? Less dense? When will a body float? Why? When is a floating body in *stable equilibrium?* Examples.

placed water, than in either of the others. And, unless the two centers were in the same vertical line, the *weight* and the *upward pressure* would not exactly oppose each other, and the body would roll. It is often necessary to *ballast* ships, that is, to place stones or iron in the lowest part, in order to render their equilibrium sufficiently stable. A life-preserver for a person's body should be attached *at* or *above* the waist, so as to keep the head above water.

161. Since pressures on a surface vary as the depth alone, a body may float in a very small quantity of water by being in a reservoir slightly larger than itself. Thus, a ship is floated by a few hogsheads of water in a dock whose form is adapted to it (Fig. 80). In such a case, the phrase "displaced water," obviously means the water which would be sufficient to fill the space occupied by the immersed part of the body.

Fig. 80.



162. A body of the heaviest materials can float, if its form is such as to exclude the water from its upper surface, till it sinks deep enough to displace its weight of water. Ships are built of iron, and their whole cargo may be specifically heavier than water, and yet they float in safety so long as the water is excluded from the deck.

163. *Specific gravity.*—The *specific gravity* of a body is its weight compared with that of some standard. Water is

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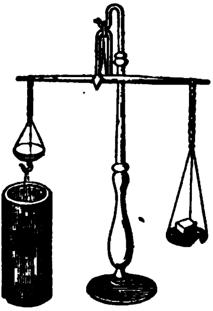
Why is *ballast* used in a ship? How should a *life-preserver* be attached? How may substances heavier than water float on water? Illustrate by iron ship. Define *specific gravity.*

used as the standard for solids and liquids, and air for gases. The number 1 being used to express the weight of a certain volume of water, if another substance of the same volume is found to weigh 4½ times as much, then 4.5 is the specific gravity of that substance. *The specific gravity of any substance is found by dividing its weight by the weight of the same volume of water.*

164. *Specific gravity by the balance.*—1. If a solid is heavier than water, *divide its weight by its loss of weight in water.* (Fig. 81.) For its loss of weight is equal to the weight of the same volume of water (Art. 158).

Fig. 81.



2. If the body is lighter than water, it may be attached to a heavier body already weighed in water. It now loses all its own weight and occasions some loss in the heavy body. Its own weight, plus the loss in the other body, equals the weight of the displaced water. Therefore, *divide the weight of the body, by its weight added to the loss it occasions to a heavier body previously balanced in water.*

3. For a liquid, *weigh equal volumes of the liquid and of water, and divide the former by the latter;* or, *weigh a heavy body in each, and divide the loss in the given liquid by the loss in water.*

165. *Specific gravity by the hydrometer.*—In commerce and the arts, it is more convenient to use instruments specially

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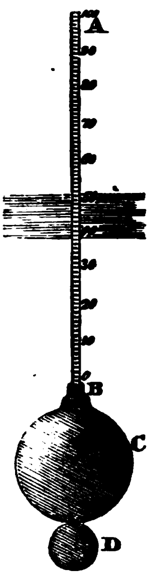
What is the standard in different cases? What number is used for the standard? Give an example of specific gravity. Show how to find specific gravity by the *balance. First* case. *Second* case. *Third* case. What method is preferred to this? What is a *hydrometer?*

contrived for obtaining specific gravity. These are called in general, *hydrometers;* but other names are given to such as are limited to particular uses; as, for example, the *alcohometer*, for testing the purity of alcohol; the *lactometer*, for milk, &c. Fig. 82 is a frequent form, used for finding the specific gravity of liquids. It consists of a hollow ball with a long, slender stem; and since it will sink until it has displaced a quantity of liquid equal in weight to itself, it will, of course, sink deeper, as the liquid is lighter. The graduation on the stem indicates the specific gravity of a liquid, by the mark to which it sinks.

Fig. 82.



166. *Tables of specific gravity.*—The heaviest substance known is the metal *platinum*, whose specific gravity is 22; the lightest is the gas *hydrogen*, whose specific gravity compared with water is only 89 one-millionths. Therefore, the ratio of the lightest to the heaviest is about 1 : 247,000, and between these limits the specific gravities of all known substances are ranged. The following table presents a few from among solids and liquids.

Platinum	22.00	Iron	7.78
Gold	19.25	Zinc	7.00
Mercury	13.58	Diamond	3.53
Lead	11.35	White marble	2.84
Silver	10.47	Glass	2.49
Copper	8.90	Ivory	1.92

Describe the hydrometer for liquids, and its use. What is the *heaviest* substance? The *lightest?* Give the specific gravity of each. The *ratio* of their gravities. State the specific gravities of some common substances. Classify some of them. Metals, gems, &c.

Sulphuric acid	1.84	Bordeaux wine	0.99
Lignum vitæ	1.34	Olive oil	0.91
Milk	1.03	Pure alcohol	0.79
Sea-water	1.03	Ether	0.71
Pure water	1.00	Cork	0.24

The common metals range from		7 to 22.
The precious gems	“	3 to 4.
The rocky substances	“	2 to 3.
The acids	“	0.7 to 1.9
The oils	“	0.9 to 1.
The woods	“	0.24 to 1.34

167. The human body, with the lungs inflated, is a little lighter than water. Rocks and stones, being generally a little more than twice as heavy as water, lose near half their weight when in water, and therefore are handled with far more ease there than in air.

168. The *magnitude* of an irregular body is accurately obtained by finding its loss of weight in water. For this loss is the weight of the same bulk of water; and since we know that 1,000 ounces of water are contained in one cubic foot (=1,728 inches), we readily find the number of *cubic inches* in the weight of the displaced water; and this is the magnitnde of the body.

169. *Questions for practice.*

1. The bottom of a reservoir is 17 ft. square, and the depth of water in it is 21 ft.; what is the pressure on the bottom?
Ans. 379,312.5 lbs.

2. The perpendicular side of a cistern full of water is 16 ft. wide, and 12 ft. high; what pressure is there against that side?
Ans. 72,000 lbs.

3. A mineral weighs 960 grains in air, and 739 in water; what is its specific gravity? *Ans.* 4.343.

The human body. Lifting rocks under water. What easy way of finding the magnitude of an irregular body?

4. An irregular fragment of stone loses 5,346 ounces when weighed in water; how large is it? *Ans.* 9,238 cub. in.

CHAPTER II.

LIQUIDS IN MOTION.

170. *Hydraulics*, or the science of *the motion of liquids*, discusses such topics as, the discharge of water from orifices; its flow in pipes and canals; its use as a motive power; its undulation in waves; and the resistance which it opposes to the motion of solid bodies.

171. *Velocity of discharge.*—If water is drawn from an aperture in a reservoir, the *velocity*, and therefore the *quantity* of discharge, *varies as the square root of the depth.* So that, if water is taken from an orifice two feet from the surface, and it is required to draw it off *three* times as fast, an orifice of the same size must be made at *nine* times the depth, that is, eighteen feet.

172. It is in consequence of this law, that if the discharged stream is projected upward, it would rise as high as the surface in the reservoir, were it not for obstructions arising from friction and resistance of the air. The jets in city water-works are usually sustained by the hydrostatic pressure from a reservoir in which the water level is higher than the jet.

Define *hydraulics*. What subjects are discussed under it? How does the velocity of discharge vary? Give an example. How high can a projected stream rise? Does it rise so high in fact? Why not?

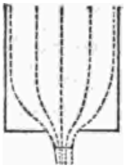
173. *Artesian wells* are wells bored into the earth, till a spring is reached from which water is thrown to the surface. From some such wells, the jet rises 50 or 100 feet into the air. The force, in these cases, is the hydrostatic pressure of water in mountains, often far distant.

174. Since the velocity of a falling body varies as the square root of the distance, it is in theory immaterial, whether water is taken upon a wheel from a gate at the same level, or allowed to fall upon it from the top of the reservoir. In practice, however, the former is best, on account of the resistance which water meets with in falling through the air.

175. *Descent of surface.*—When water is discharged from the bottom of a vessel, whose size is the same from top to bottom, the surface descends with a *uniformly retarded* motion, because of the law already mentioned, that the velocity varies as the square root of the depth. And if such a vessel empty itself, one-half as much water will be discharged as there would be in the same time, the vessel being kept full; because, in the latter case, the greatest velocity is preserved uniform during the whole time.

176. *Condition of orifice.*—The quantity discharged at a given depth below the surface depends on some other circumstances, besides the size of aperture. If the orifices in figures 83, 84, and 85, be of the same size and at the same depth, still the water discharged in a given time is not the same. The dotted lines show

Fig. 83.



Describe the artesian well. What force raises the water? In what two ways may water be taken upon a wheel? Which is best in *theory?* In practice? Why? How does a surface descend when water is drawn off from a prismatic vessel? Compare the quantity when it is emptied and when kept full. What circumstances besides depth affect the rate of discharge?

how the particles converge towards the aperture. In Fig. 83, they continue to converge a little beyond the point of discharge, and thus diminish the stream. In this case, where there is a simple aperture through the thin wall of the vessel, there is about *two-thirds* of the calculated discharge. But if the wall of the vessel is curved in the same form as the lines of the particles down to the narrowest part of the stream, as in Fig. 84, the discharge will very nearly equal that which is obtained by calculation. But if the inner surface curves as in Fig. 85, so as to form a pipe directed inward, there is only about half as much discharged as calculation gives.

Fig. 84.

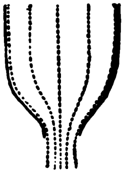
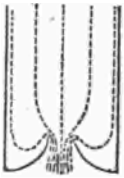


Fig. 85.



177. *Aqueducts.*—As has just been stated, a short pipe, conformed to the shape of the stream, very much increases the rate of discharge; but any considerable length of pipe diminishes the flow in proportion as the pipe is longer. The water is supposed to be hindered by friction on the sides of the pipe. Therefore, the longer an aqueduct pipe is, the larger it must be, or else the higher the level in the reservoir, in order to convey the same quantity of water.

178. An aqueduct should be as nearly straight as possible, not only to avoid unnecessary length, but because the force of the current is diminished by all changes of direction. If there must be change, it should be by a gentle curve, and not by an angle. Velocity is lost also by enlargement and diminution in the size of the pipe.

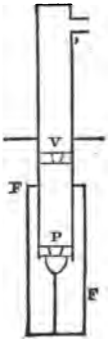
Compare the different cases described. What is the effect of a long pipe? How remedied? How should aqueduct pipes be laid?

179. *Rivers.*—Friction and change of direction have great influence on the flow of rivers. Were it not for existing obstructions, the water, in its descent on an inclined plane, would be constantly *accelerated.* But after a certain velocity is acquired, the force of gravity, which urges its descent, and the impediments which tend to stop it, neutralize each other, and the motion is nearly uniform. The largest rivers in the world descend about five or six inches in a mile.

180. *Hydraulic Instruments.*—Some hydraulic instruments are for the purpose of raising water, and others for moving machinery by the force of water.

181. The *lifting-pump* (Fig. 86) consists of a tube, in which is a valve V, below the level of the water, and opening upward. The piston P, is below V, and has a valve in it also opening upward. The piston is moved up and down by a frame F F, which is worked by a lever and rod on the outside of the pump, not represented in the figure. The water, by its own pressure, rises through the valves to the same level as on the outside. When the piston is lifted, it pushes the water before it through V, which secures it while the piston descends; and on rising again, the piston pushes still more, and so on, till the water reaches the spout.

Fig. 86.



182. The *chain-pump* consists of an endless chain with circular disks attached to it at intervals of a few inches, which raise the water before them in a tube, by means of a wheel,

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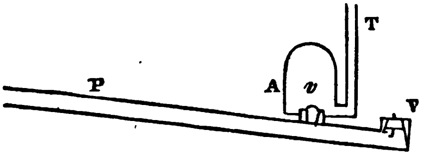
What circumstances affect the flow of *rivers?* What *would* be the motion otherwise? When will the motion become uniform? What is the descent in the largest rivers? Hydraulic instruments are for what purpose? Describe the *lifting-pump.* The chain-pump.

over which the chain passes; the wheel may be turned by a crank. The disks cannot fit closely in the tube without causing resistance; hence the water will soon descend to the level in the well, after the pump ceases working, and a certain velocity is requisite in order to raise it to the place of discharge.

Most pumps employ atmospheric pressure in their operation, and will be described among *pneumatic instruments.*

Fig. 87.

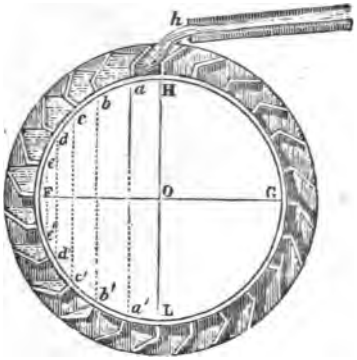


183. The *hydraulic ram.*—Fig. 87 shows the essential parts of this instrument, which is used to *raise water by the force of water.* P is a long descending pipe, containing at the lower end a valve, V, which opens downward. As the water pours out at V, its velocity increases until the momentum becomes sufficient to raise the valve, and close the pipe. As water is nearly incompressible (Art. 143), the shock of the whole moving column comes in one sudden impulse, and pushes open the valve *v*, rushes into the air-chamber A, and up the pipe T. When the momentum is expended, the valve V drops by its weight, and the current begins to run out once more, till the same effect is repeated. A part of the water may in this way be raised many feet above the level of the reservoir, while the other part runs to waste.

184. *Vertical water-wheels.*—These are of three kinds, *overshot*, *undershot*, and *breast-wheel.*

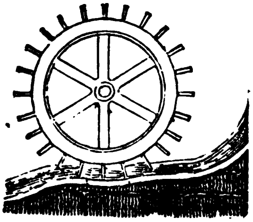
Why may the disks not fit the tube closely? By what agency is water raised in the use of the *hydraulic ram?* Describe the instrument. How many, and what kinds of *vertical* water-wheels?

Fig. 88.



The *overshot wheel* (Fig. 88) has buckets on its circumference, which receive the water just after passing the highest point, and empty themselves at the bottom. The *weight* of the full buckets on one side, while those on the other side are empty, gives motion to the wheel. This kind of wheel can be used when the quantity is small, provided the fall is considerable, so as to give room for a wheel of large size.

Fig. 89.



185. The *undershot wheel* (Fig. 89) is carried by the momentum of running water, which strikes the paddles of the wheel on the under side. It is used in situations where the quantity of water is large, but the fall is small.

186. The *breast-wheel* (Fig. 90) is carried partly by the weight, and partly by the momentum of the water, which is received on the floats of the wheel at the height of the axis, and confined between them by the masonry of the water-course.

187. *The turbine.*—This is a horizontal wheel, now much

Describe the *overshot wheel.* When used? The *undershot.* When used? What force in each case moves the wheel? Describe the *breast* wheel. Describe the *turbine.*

Fig. 90.

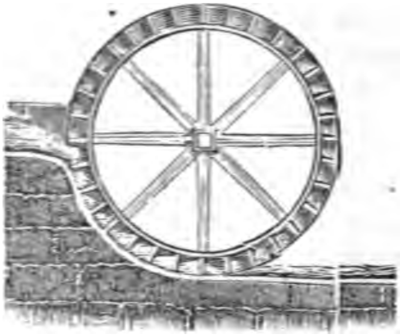
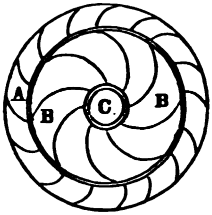


Fig. 91.



used, and very effective. Fig. 91 is a horizontal section of the wheel and reservoir. B B is a cylindrical reservoir of such height as to contain the required depth of water. The curve lines in it represent partitions occupying the lower part, and giving an oblique direction to the water as it issues. The orifices of discharge are around the sides of the reservoir, close to the bottom, and the wheel A surrounds these openings; the floats of the wheel are curved in a direction opposite to that of the partitions, so that the streams strike them perpendicularly. The wheel is closed on the upper and outer sides, but open underneath, and thus the water falls as soon as it has produced its impulse. The spokes of the wheel pass under the reservoir to the axis C, which rests in a socket on the ground, and passes up through an open tube in the center of the reservoir. As the reservoir can have no support at the bot-

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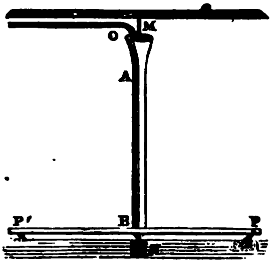
The use of the partitions? The form of the paddles? How is the reservoir supported?

tom, it is suspended by a strong flange near the top, upon the masonry which surrounds the wheel.

Fig. 92.



188. *Barker's mill.*—This machine operates by means of unbalanced pressure. A B (Fig. 92) is a hollow cylinder movable about a vertical axis M N. P P′ is another cylinder connected with the former at right angles near the bottom. Near the extremities are the openings P and P′, one towards the observer, the other on the opposite side. The cylinders are kept full of water by the pipe O; and as the water flows from P and P′, the unbalanced pressure on the sides of the cylinder opposite to these openings, acts on the arms P B, P′ B, tending to cause revolution about M N. This contrivance is advantageously used to carry machinery.

CHAPTER III.

CAPILLARITY,—RESISTANCE OF FLUIDS,—WAVES.

189. *Adhesion.*—All liquids show more or less attraction among their particles. It is this force which causes them to assume the *spherical* form when in small masses, as rain-drops in the air, and dew-drops on a spider's web, and mercury when ly-

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Describe Barker's mill. What is the force employed? When does a liquid assume a *spherical* form, and why?

ing on almost any substance. But there is also a tendency in liquids to adhere to other bodies with more or less force. In the case of water, it appears in the fact, that it *wets* most substances which it touches; that is, a thin film of the water attaches itself to them. It also *rises above its level* about most substances, forming a curve concave upward, as, for example, against the glass in a tumbler. But the attraction among the particles of mercury is so strong that it draws away from glass, and is rounded on the edge, when standing in a glass vessel.

190. *Capillary action.*—This name is given to the effect which *fine tubes* produce in raising or depressing liquids within them. Whenever a liquid *wets* a solid, it will *rise* above its level in a fine tube made of that solid; as is the case with water and glass. But when a liquid has so strong attraction among its own particles that it will *not* wet a substance, then it will be *depressed* in a tube of that substance; thus, mercury will not spread itself in a film over the surface of glass, as water does, and it is depressed in a fine glass tube, while water is raised.

The finer the tube, the greater is the elevation or depression of a given liquid, the *distance* in each case *varying inversely as the diameter* of the bore.

The height to which a liquid is raised does *not* depend on its weight; for alcohol, though lighter than water, is not raised half so high in glass.

Between *parallel plates*, a liquid rises half as high as in a tube of the same diameter. If the plates are inclined to a vertical

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Compare the attraction between the particles of *water*, and their attraction for other substances. Give the proofs. Case of *wetting*. Rising in vessels. Make a like comparison for *mercury*. Capillary action, what is it? When *rise?* When *descend?* How does height vary? Is the *weight* of the liquid concerned? Capillarity in case of *plates, parallel?* also *inclined?*

edge, the top of the liquid is a curve concave upward, of the form called a *hyperbola.*

191. It is by capillary action that a part of the water which falls on the earth is kept near its surface, instead of all sinking to the lowest strata of the soil. This force aids the ascent of sap in the pores of plants. It lifts oil between the fibres of the lamp-wick to the place of combustion. Cloth readily imbibes moisture by its numerous capillary spaces, so that it can be used for wiping things dry. If paper is *unsized*, it also imbibes moisture quickly, and can be employed as *blotting-paper*, but when the pores of paper are filled with sizing, to fit it for writing, it absorbs moisture only in a slight degree, and the ink which is applied to it in writing must dry by evaporation.

192. *Resistance to motion in a fluid.*—The resistance which a body encounters in moving through any fluid, arises from the inertia of the particles of the fluid, their want of perfect mobility among each other, and friction. No definite calculation can be made, except for the first of these. So far as *inertia* alone is concerned, *resistance varies as the square of the velocity.* So that, if a body moves in a medium with *twice* the velocity of another similar body, it is resisted *four* times as much; if five times as fast, it meets twenty-five times the resistance, and so on.

193. This result of calculation is confirmed by observation in the case of moderate velocities, as in the motion of boats in water. But in very swift motions, like that of a cannon-ball in the air, the resistance increases at a much faster rate.

The resistance in water is great, with any velocity, because of its density. This is seen in the fact that a wind, which

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Examples of capillary action: earth, lamp, cloth, paper. Name the causes of resistance to motion in a medium. How does resistance vary? Illustrate. When is this law most nearly true? Show that the resistance in water is always great.

moves sixty miles an hour, will not drive a sail-vessel more than twelve or fourteen miles per hour. And, since the resistance increases by a rapid law, great speed in steamships cannot be attained, except by a wasteful expenditure of force. The resistance of air is vastly less than that of water, and the principal obstruction on railroads arises, not from the resistance of the air, but from the friction of the rails.

194. When a body falls through the air, its motion, instead of being *uniformly accelerated*, as it would be in a vacuum (Art. 56), at length becomes *uniform*, owing to the fact, that with the increase of velocity, the resistance increases so much faster, as finally to equal the force of gravity; it is then like a moving body not acted on by any force, and therefore maintains a uniform motion. Atwood's machine (Art. 63) owes its utility in part to the law now considered; for if the bar falls ten times slower than in free fall, it is 100 times less obstructed, and the resistance becomes insensible.

195. *Waves.*—Waves are moving elevations of water, produced by a force which acts unequally on the surface. If a stone is thrown upon water, it depresses the surface and crowds up the surrounding water in a ring above the level; as this sinks, it acquires a momentum, which carries it below the level, and this causes the next portion to rise above the level. Thus a circular wave is continually spreading from the center where the stone fell. But this is not the whole effect; for after the elevated ring has descended below the level, it returns again with a momentum which once more carries it as far above. So that, at every point, the wave is continually renewing itself, and

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What is the principal obstruction on railroads? Is a body *uniformly* accelerated in falling through the air? Why? What motion is finally acquired? What circumstance renders Atwood's machine useful? What are waves? State how a stone causes them.

the water is covered with a *system* of circular waves, expanding outward more and more. As they increase their distance from the center, they become lower, and at length are too slight to be seen.

196. The *length* of a wave is the distance from one summit to the next, measured in the direction in which the wave moves. The corresponding parts of different waves are called *like phases;* as, for instance, the *summits* of two waves are like phases. And *opposite phases* are those parts in which the motions of the water at any instant are in contrary directions; thus, a point half way down the front of a wave, and another half way up the rear of the next wave, are opposite phases. The distance between *like* phases is *one*, *two*, or more, whole wave lengths; the distance between *opposite* phases, is a half, or some number of wave lengths and a half.

197. *The progressive motion of water an illusion.*—If what has just been stated is true, then, though the waves move along the surface, yet the water itself does not, but only rises and falls in its place. As new portions of the water rise in regular succession to the same height, and then sink again, the eye cannot distinguish this succession from the onward movement of the same mass of water. When waves are running over the water, a block of wood rises and falls without being borne along; whereas, if the water itself was advancing, the block must advance with it. So, when a ship is between two waves, one of them presently passes under and elevates it, instead of carrying it along between them. On a beach, however, where the columns do not find room to descend, the water is driven

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How does the height change in the larger circles? What is the *length* of a wave? What are *like* phases? *Opposite* phases? How far apart in each case? Explain the appearance of progressive motion of the water. Show that it is not real. Is it so on a beach?

forward upon the shore, and the character of the waves is changed.

198. *Sea-waves.*—These are produced by the wind, which acts by friction on the surface of smooth water, raising a ridge, which by its weight sinks and commences a series of oscillations, which are propagated onward in the manner already described. And so long as the wind continues, its action is repeated on every wave as it rises, so that the height is increased. The water is rarely disturbed as much as twenty feet below the level. But if the trough between two waves were twenty feet *deep*, the *height* of the waves (from trough to summit) would be forty or fifty feet high.

199. *Compound systems of waves.*—It is rare that a system of sea-waves exists alone; there are usually two or more systems combined. It is frequently observed that in sea-waves there is a succession of higher, and then lower waves, with some degree of regularity. This is owing to the co-existence of two systems of waves of different lengths on the same surface. Where the phases of one system coincide with the *like* phases of the other, there are high waves; and where they coincide with the *opposite* phases of the other, there are low waves, or possibly no waves at all. By careful experiment it is possible to show that two systems of waves may totally destroy each other. This happens when the waves of the two systems are of exactly the same length and height, and one system is *half* a wave length in advance of the other, so that opposite phases coincide. For the summits of each system fall in with the basins of the other system, and thus they neutralize each

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How are *sea-waves* produced? How deep is the water disturbed? How high would waves be? Does *one* system of waves commonly exist alone? What is the effect? Where do the *high* waves occur? The *low* ones?

other, producing level water. When two pebbles are thrown on still water, at a little distance from each other, lines of high waves, and also lines of level water, may be traced among the two systems of rings. The various *resultant effects* of different systems of waves are called *interference of waves.*

State the effect of *two* pebbles thrown *on water.* Where are the lines of level water? What is *interference of waves?*

PART III.—PNEUMATICS.

CHAPTER I.

MECHANICAL PROPERTIES OF AIR.

200. *Gases and vapors.*—The compressible fluids are usually subdivided into two classes, *gases* and *vapors*. Those which can be readily reduced to the liquid or solid forms, are called *vapors*, and the others are called *gases*. Thus, *steam* is the vapor of water. The *air* is a gas, having never been reduced to any other than a gaseous form; *carbonic acid* is also called a gas, though it can with difficulty be reduced both to a liquid and a solid form.

Among the particles of a gaseous body there is a mutual *repellency*, which causes it to expand as fast as the compressing force is removed.

201. *The air material.*—The air has the common properties of matter. It obviously has *extension*. It is also *impenetrable;* for, though very compressible, it always occupies space from which it excludes all other matter. That it has *weight* is ascertained by weighing a vessel when full of air, and again when empty. It shows its *inertia* in the strength of wind, which is air in motion, and in resisting the motions of other bodies through the air. Air is also visible when we look through a great extent of it; we see its true color in the azure of the sky.

How are the compressible fluids divided? State the difference between a *gas* and a *vapor*. Examples. How do the particles of a gaseous body affect each other? Show that air is material. How is it *weighed?* What is its *color?*

202. *Tension of the air.*—The expansive force of a gaseous body is called its *tension.* If the temperature remains the same, this force becomes more feeble as the gas is expanded, and more powerful as it is compressed, according to a very simple law, namely: *the tension varies inversely as the volume.* Thus, at a given temperature, if a cubic foot of air is expanded to *two* feet, it has only *half* as much tension; if it is enlarged to *ten* feet, its tension is *one-tenth* as great. On the other hand, if air is compressed to *one-half* its former volume, its tension becomes *twice* as great as before, and if to *one-third, three* times as great, and so on. Since the tension must always equal the compressing force, it follows that *the volume is inversely as the compressing force.* This is known as *Mariotte's law,* from the name of the discoverer.

203. *The diving-bell.*—Mariotte's law is well illustrated by the diving-bell, a very useful invention, employed either for laboring or exploring under water. It is a large iron box, which is let into the water with the open side downward, by a tackle of pulleys. When it first enters the water, it is full of air of the common tension. But after descending about thirty-four feet, it is only half full of air. It is known that at the depth of thirty-four feet the pressure of water is equal to the weight of the atmosphere. Therefore, when thirty-four feet deep, the air of the diving-bell is subjected to a pressure of *two* atmospheres, the weight of the water and of the air above it. Thus, under *twice* the pressure, the air occupies *half* the space. At the depth of sixty-eight feet the compressing force is equal to *three* atmospheres, and the air fills only *one-third* of the bell. Since the

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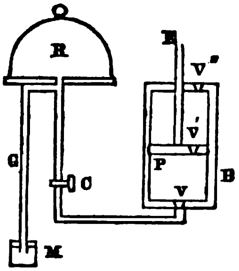
Define *tension.* Give Mariotte's law. Illustrate it. Describe the diving-bell, and state how it proves Mariotte's law. What depth of water is equal to the weight of the air?

diving-bell fills up with water in this manner, it is necessary to force down air through hose by a condenser, and also for the purpose of supplying pure air, while the impure is let off by a stopcock.

204. *The air-pump.*—This instrument, which is indispensable in pneumatic experiments, is used for removing the air from a receiver. It has a great variety of forms; but the following general description will apply to them all. B (Fig. 93) is a cylindrical *barrel* in which the piston P works air-tight by means of the rod E. In some pumps the piston-rod is raised and depressed by a lever, in others by a rack and pinion. From the bottom of the barrel, a pipe V C passes to the *pump-plate*, on which stands the glass receiver R. The plate and receiver are both ground to a perfect plane, so as to fit with an air-tight joint. That end of the pipe which connects with the barrel is covered with a valve V; in the piston is also a valve V′; and in some pumps there is a third V″ at the top, all of which open upward, that is, *from* the receiver *toward* the open air. G and M are the pipe and cistern of the *gauge* (to be described hereafter), intended to show how far the exhaustion has proceeded.

Fig. 93.



205. *Operation of the air-pump.*—Suppose the piston to be at the top of the barrel. When it is pressed down, the air below it cannot be pushed into the receiver, because the lower valve is shut by the pressure; it therefore presses open the

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How is the diving-bell kept full of air? Describe the essential parts of the air-pump. What is its use? State how it operates.

valve in the piston and escapes into the upper part of the barrel. When the piston is raised, the air above it cannot return, but is crowded through the valve at the top into the open air; and at the same time the air in the receiver and pipe, by its tension, opens the lower valve, and is equally diffused through both receiver and barrel. Thus, *one barrel* full of the air, which was at first in the receiver and barrel, has been removed into the atmosphere; and what is left occupies the same space as the whole did before. If the piston is once more depressed and raised, the same operation is repeated; and after several strokes, more or less, according to the size of the receiver, the air is nearly all removed. Many pumps have two barrels, the piston of one ascending while that in the other descends.

206. The plan of the instrument implies that air always tends to expand, so as to occupy the vacant space to which it has access; else it would not pass from the receiver into the barrel every time the piston is raised.

The air-pump cannot produce a *perfect vacuum*, because only that fraction which is in the barrel can at any stroke be taken out; but, with a good pump, so near an approach to a vacuum can be made, as to answer every purpose of experiment.

By means of the air-pump, a great variety of experiments can be performed, to prove the pressure, weight, and tension of the air, and to illustrate these and other properties in many ways.

207. *The Magdeburg hemispheres.*—Among the earliest pneumatic experiments performed after the invention of the air-pump, was that of the Magdeburg hemispheres, so named

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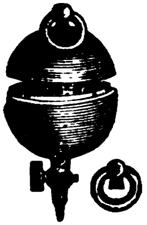
When the piston descends. When it ascends. What property of air is illustrated in the operation? Can the vacuum be complete? Why? What properties are proved by the pump? Describe the *Magdeburg* hemispheres.

Fig. 94.



from the city where the experiment was first devised. They consist of two brass hemispheres (Fig. 94), which are fitted together with an air-tight joint; the air is exhausted from them by the pump, and then force is applied by the handles to pull them apart. A pair of *four* inches in diameter requires the weight of a heavy man to separate them. They illustrate the pressure of the atmosphere exerted in all directions.

208. *Buoyant power of air.*—It is true of air as well as of water, that it exerts a *buoyant* power on every thing in it, by the excess of the upward over the downward pressure. It is shown by the air-pump, that a body weighs more in a vacuum than in the air. This is more apparent in the case of a body having considerable bulk, since the loss always equals the weight of displaced air.* Hence, if a large and a small body *balance* each other in the air, the large one will *preponderate* in an exhausted receiver, being really the heavier body. This buoyant power will cause a body which is specifically lighter than air, to ascend. A balloon, filled with hydrogen, may be made so light as to ascend, even when loaded with the weight of a car containing a number of persons.

209. *The air-condenser.*—While the air-pump shows the tendency of air to *dilate* without limit, as the compressing force of the air is removed, the air-condenser exhibits the indefinite *compressibility* of air. The pump would be changed to a condenser by reversing all its valves, and confining the re-

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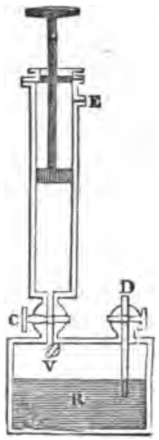
What force will separate a pair four inches in diameter? What do they show? How much weight does a body lose in air? If a large and a small body balance in air, will they in a vacuum? Why? Why does a balloon ascend? What property of air is shown by the condenser?

Fig. 95.



ceiver to the plate by a strong frame. Let R (Fig. 95) represent a strong metallic receiver, into the top of which is screwed the barrel of the condenser. At the bottom of the barrel is the valve V, opening downward; there is another in the piston opening downward (not represented), while a small opening E admits the external air to the top of the barrel. While the piston is raised, the air above it passes through the piston-valve into the lower part by atmospheric pressure. When it is depressed, its valve shuts, and it crowds the air before it into the receiver; and in the mean time, the outer air fills the barrel by pressing through E. When the piston is lifted again, the compressed air in R shuts the valve V by its tension, and the operation is repeated. The figure represents a small instrument with a solid piston; for in such a case, the weight of the air can be lifted, till the piston is above the aperture through which the air enters.

210. The air thus condensed in the receiver can be made to exhibit its increased tension in many ways; one of these is by throwing a jet of water with great velocity. Let the receiver be partly filled with water, and a jet pipe screwed into the top, reaching near to the bottom; then, after condensing the air, on opening the stopcock D, the water will be thrown to a height corresponding to the tension of the compressed air.

211. *The barometer.*—This instrument furnishes a *measure* of the atmospheric pressure. A glass tube, three feet long, and

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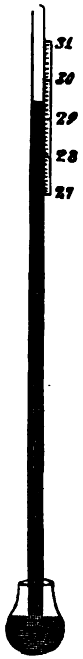
How is it constructed? Describe its operation, both in the descent and the ascent of the piston. Describe the arrangement for throwing a jet.

Fig. 96.



closed at one end, is filled with mercury and inverted in a cup of the same fluid, as in Fig. 96. The column will sink a little from the top, and then remain at the height of about thirty inches above the level in the cup. It was ascertained by *Torricelli* of Italy, in 1643, that the mercury is sustained in the tube by the pressure of the air. Hence, the experiment is known as *Torricelli's experiment.* The space above the mercury in the top of the tube is the most perfect vacuum which can be formed, and is called the *Torricellian vacuum.*

212. The mercury in the cup could not remain level, unless equal weights rested on all the equal parts of it; therefore, the weight of mercury in the tube which stands on one part, exactly equals the weight of air which rests on every other equal part. Thus, by weighing the mercury in the tube above the level of that in the cup, and measuring the internal area of the end of the tube, we may determine the weight of air on a square inch. This is found to be 14.7 lbs., varying somewhat at different times.

213. If the foregoing experiment is performed with water instead of mercury, it is found necessary to use a tube near forty feet long. The height of the column of water above the level in the reservoir is about thirty-four feet; for, since the specific gravity of water is 13.58 times less than that of mer-

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Describe the *Torricellian* experiment. What is the Torricellian vacuum? To what is the weight of mercury in the tube equal? What is the weight of air on a square inch? How high a tube would be required to perform this experiment with water? Why is the water-column so much higher than mercury?

cury, it requires a column 13.58 times as high to produce the same pressure, that is, to balance the weight of the atmosphere.

214. If a scale of inches and decimals be attached to the tube, to show the changes which occur in the height of the mercurial column, the apparatus which has been described becomes a *barometer*, an instrument which is in very general use for giving indications with regard to the weather.

215. *Changes in the barometer.*—At the level of the ocean the mercury of the barometer is on an average about thirty inches high, in every part of the world. But if it be carried to higher places, the column falls as the height is increased. For it is only the air *above* the instrument which holds up the mercury; and the quantity above becomes less, the higher it is carried. On the tops of the highest mountains, the column is shortened several inches; and a barometer has been carried up in a balloon to such an elevation that the mercury fell to twelve inches.

216. *Changes in the stationary barometer.*—A barometer which is *stationary*, is also continually changing with the hour of the day and the state of the weather. The *diurnal* oscillations are small, but in tropical countries they are very regular. The mercury is highest from nine to ten o'clock, and lowest from three to four, both morning and evening. In the temperate zones, the changes which are connected with states of weather so far exceed the hourly movements, that the latter are hardly noticeable. When a storm is coming on, the mer-

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What more is necessary to render the basin and tube of mercury a *barometer?* Give the average *height* of the barometer. State the effect of carrying the instrument higher. Why? What other things besides altitude cause the barometer to change? At what hours is the barometer highest? Lowest? *Where* are these diurnal movements most regular? How do storms affect the instrument?

cury generally falls, and, as it passes off, the column rises again; and during the year, the extent of such changes amounts to *two* or *three* inches, while within the tropics the annual range is only about *one-fourth* of an inch.

217. For scientific purposes, great care is used in constructing a barometer, that air and vapor may be excluded from the space above the mercury, and that the scale may give true indications of atmospheric pressure. To secure the latter, adjustments have to be made for temperature of the mercury, for capillarity, and for changes of level in the cup. When observations made at different places are compared, allowance must also be made for altitude above the ocean.

218. *Gauge of the air-pump.*—As the gauge of the air-pump is a barometer, it is properly noticed in this connection. One arrangement is represented in Fig. 93. The graduated tube G is thirty-two or thirty-three inches long, the upper end opening into the receiver, and the lower extending into a cup of mercury, to which the external air has access around the tube. Before the exhaustion commences, the mercury in the cup and that in the tube are on the same level. But as soon as some air is removed from the receiver, the pressure in the tube is diminished, and the weight of the external air raises the column, as in the barometer tube. If a complete vacuum could be formed, it would be indicated by the mercury in the tube standing as high as the barometer at the same time.

There are also other forms of gauge, in which, the tube being already filled, the process of exhaustion diminishes pressure in the cup, and allows the mercurial column to fall.

Where is the *range* greatest? Care necessary in making a barometer? Adjustments? Describe the gauge of the pump, and its operation. What other kind is used?

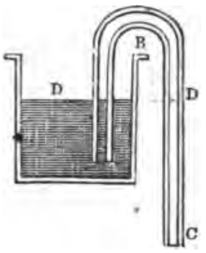
CHAPTER II.

MECHANICAL AGENCIES OF AIR AND STEAM.

219. In consequence of our power of forming a vacuum, and of employing the expansive force of air and steam, their aid becomes available in many kinds of machinery.

220. *The siphon.*—This instrument is simply a bent tube for conveying a liquid over the side of a vessel or reservoir to a lower level than that within the vessel. Thus, if the bent tube be filled, and then inverted, as in Fig. 97, the liquid will continue to run so long as the outer end is lower than the surface within. This is owing to the fact that the atmosphere will sustain a column of liquid in a tube. The pressure of the air at the outer end C is sufficient to support a column of water thirty-four feet high, and the pressure at D, within the vessel, could also do the same; but the former pressure has to support the column from C to B, while the latter supports only the column D B; hence there is an excess of atmospheric force pressing from the inner to the outer extremity, and that excess is greater (and therefore the velocity greater) according as the height of the outer column is greater than that of the inner.

Fig. 97.

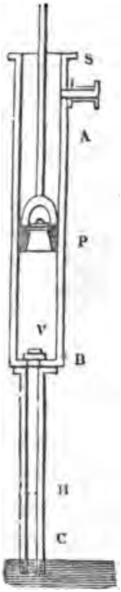


221. It is obvious from the foregoing explanation that wa-

Describe the siphon. Show how the water *ascends.* On what does the velocity of discharge depend? What is the greatest height the water can reach? Why?

ter will not in this way ascend more than thirty-four feet, since that is the limit to which the air can sustain a column of water. Water may be taken out of a well or over a hill by a siphon, if there is opportunity to discharge it at a lower level. But the instrument is principally employed for decanting liquids from one cask to another, without disturbing the sediment.

Fig. 98.



222. *Pneumatic pumps.*— The pumps for raising water, which are in most common use, operate on the principle of forming a vacuum in a pipe, into which water is then raised by atmospheric pressure. The vacuum may be formed in many ways, but most conveniently by the *piston*, which is therefore generally used.

223. *The suction-pump* (Fig. 98) has a valve V, less than thirty-four feet above the water C, and another valve in the piston P, both opening upward. The piston is usually raised and lowered by a lever. When the piston *is raised*, the air resting on it is lifted, and that below, occupying a larger space than before, loses some of its tension; hence the atmosphere on the outside of the pipe presses water into it, till the weight of the water and the tension of the air above it together balance the atmosphere. When P *descends*, it allows the air above V to pass through it; and when lifted again, the water rises higher for the same reason as before, till at length the water comes above V, and the piston dips into it. After that, all the water above the piston is

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The use of the siphon? State the principle of water-pumps. What is the usual way of forming the vacuum? Describe the *suction*-pump. What takes place as the piston rises? As it descends?

directly lifted by it, and the whole space below is kept full by the pressure of the external air.

224. *The forcing-pump* (Fig. 99) has a valve V exactly as in the suction-pump. But the piston is solid, and the second valve V′ is just above the lower one, opening outward into a side pipe, in which the water rises. In the *ascent* of the piston, the same effect is produced as already described; but in its *descent*, after the water has once filled the tube above V, it is driven through V′ up to the place of discharge.

Fig. 99.

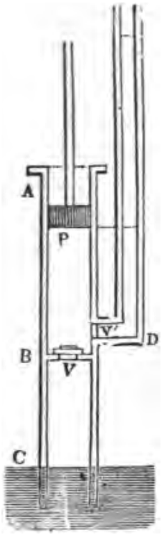
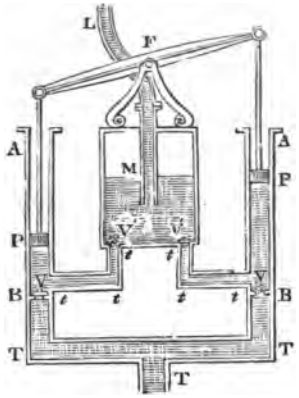


Fig. 100.



225. In each of these pumps, though the lower valve must be less than thirty-four feet perpendicularly from the water-level,

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21. Describe the *forcing*-pump. In what respect is it like the suction-pump? State what happens in the descent of the piston. How near the water must the *lower valve* be?

yet after the water is once above this valve, it may be raised to any height whatever.

The same force is required to raise water by a pneumatic pump, as by any other means; for the atmosphere presses up only water enough to compensate for the deficiency in the tension of air beneath the piston; and that deficiency is just equal to so much of the weight of the air above as is lifted by the piston.

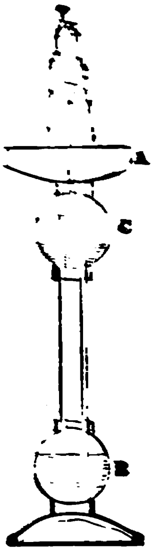
226. *The fire-engine.*—This machine generally consists of one or more forcing pumps, though the arrangement of parts is exceedingly varied. Fig. 100 illustrates the principles of its construction. As the piston P ascends, the water from T is raised through the valve V, by the atmospheric pressure. As P descends, the water in A B is driven through V′ into the air-vessel M, whence, by the tension of the condensed air, it is forced out through the hose L without interruption. The piston on the other side operates in the same way by alternate movements. The strength of several men may be applied at once by hand-bars called *brakes*, suitably attached to the lever F.

227. The air-vessel M is a contrivance often connected with pumps and other instruments for moving water; and has been already noticed in the description of the hydraulic ram (Art. 183). Its object is to cause the stream to flow *continually*, where the force, acting alone, would discharge it *with intermissions*. As the water is pressed into the air-vessel, it diminishes the volume of the air, and thus increases its tension; and this increased tension is a continued force which keeps the water in motion during the interruptions of the power.

Why? How high can the water be raised after passing the piston? How much force is necessary to raise water by the piston? What does the fire-engine consist of? Explain its operation. What are the *brakes?* What is the use of the air-vessel?

228. *Hero's fountain.*—The condensation in the air-vessel, from which the water is discharged, may be produced by *the weight of a column of water*. An illustration is seen in Hero's fountain (Fig. 101). A vertical column of water from the basin A, presses into the air-vessel B, and condenses the air according to the height of A B. From the top of B an air-tube conveys the force of the compressed air to a second air-vessel C, which is nearly full of water, and has a jet-pipe rising from it into the basin A. Since the tension of air in C is equal to that in B, a jet will be raised, which, if unobstructed, would be equal in height to the compressing column A B.

Fig. 101.



A machine constructed on this principle, for taking the water out of a mine in Hungary, was called the *Hungarian machine*.

229. *Steam as a power.*—At all the natural temperatures, water is slowly changed into vapor, which mingles with the air and has only a feeble tension. If the temperature is artificially raised, the vapor is called *steam*, and its tension increases at a rapid rate, being doubled on the average for every increase of 27°. When water boils in the air, its temperature is 212°, and the tension of the steam equals that of the atmosphere, or 15 lbs. per square inch. By confining

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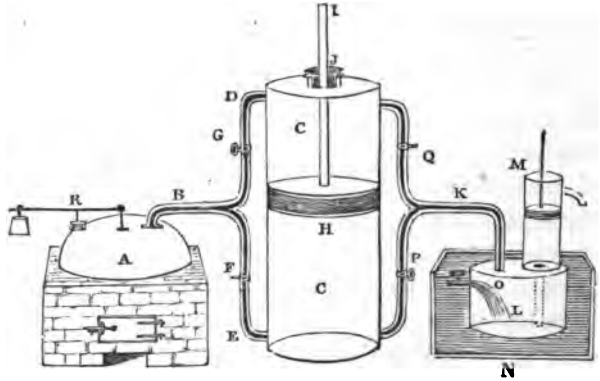
228. Explain what compresses the air in Hero's fountain. Describe it. What machine has been constructed on this principle? At what temperatures does water evaporate? 229. When is the vapor called *steam*? How often is its tension doubled? What is the temperature of water boiling in open air? What tension has the steam? How can water be boiled at higher temperatures?

water in strong vessels, its boiling temperature may be raised, and the tension of the steam increases indefinitely; it thus becomes a source of great power. Again, by suddenly cooling steam, and changing it back to water, nearly all the space which it occupied becomes a vacuum, and steam is thus *indirectly* a source of power.

230. *The steam-engine.*—After the steam-engine had been in use about fifty years, for pumping water from the mines of England, it received its great improvements in 1763, from James Watt, of Scotland. By removing the serious difficulties under which it had labored, Watt rendered the steam-engine the most valuable prime mover in the world. The first improved form was called the single-acting engine; the steam exerted its power to move the piston only in *one direction;* it thus acted at inter-

Fig. 102.



How does the tension change? In what two ways is steam a source of power? 2 Who chiefly improved the steam-engine? What was the first form of the improved engine? Why so called?

vals, and answered for pumping water, but was not well adapted for general use. He almost immediately changed it to a *double-acting* engine, under which character it is now universally known, and employed for almost every conceivable purpose. Its essential parts are exhibited in Fig. 102. A is a strong *boiler*, with a safety-valve R, through which the steam escapes as soon as its tension is great enough to lift the weight. B is the *steam-pipe*, which divides into two branches, one entering the cylinder at the top, the other at the bottom. C C is the *steam-cylinder*, in which the piston moves up and down; K is the *eduction-pipe*, leading both from the top and bottom of the cylinder to the condenser; L is the *condenser*, immersed in the cold water of the cistern N. M is a common pump, put in motion by the engine, for clearing the condenser of water or air, and is called the *air-pump*. Each of the four pipes can be opened or closed by the *valves* F, G, P, Q, which are also moved by the engine. I is the *piston-rod* (passing through the top of the cylinder at J with a steam-tight joint), by which the motion of the piston is communicated to the machinery.

231. *Operation of the engine.*—Suppose all parts of the cylinder and pipes to be filled with steam. Then, if G and P are opened, the steam from the boiler rushes into the upper part of the cylinder, tending to press the piston down; and at the same time, the condenser L being very cold, the steam in the lower part of the cylinder flashes into it, being condensed as fast as it enters, so that in an instant the space below the piston becomes a vacuum. The piston, therefore, descends by the tension of steam above it, while there is nothing below to oppose its motion. G and P are now closed, and F and Q

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2 **The second form? 3 Describe its essential parts. Explain the operation when G and P are opened. When F and Q are opened.**

opened; and immediately the condition of the top and bottom of the cylinder is reversed; steam pressing in at the bottom, and the space above being vacant, the piston ascends with the same force as that by which it was depressed a moment before.

232. That the condenser L may be sufficiently cold for condensing the steam quickly, it is not only surrounded by cold water in the cistern N, but a jet of water is at each stroke of the piston thrown into it. The pump M must therefore be constantly operating for the removal of the injected water, which arises from the condensed steam.

233. When the steam is condensed, the heat which was latent in it is liberated in great quantities, and rapidly heats the condenser and the surrounding water, so that it becomes necessary to supply the cistern constantly with cold water, for which purpose another pump is required, which is called the *cold-water pump.* A third pump, the *hot-water pump,* carries back into the boiler the heated water which has been removed from the condenser. All these pumps are kept in motion by the working-beam.

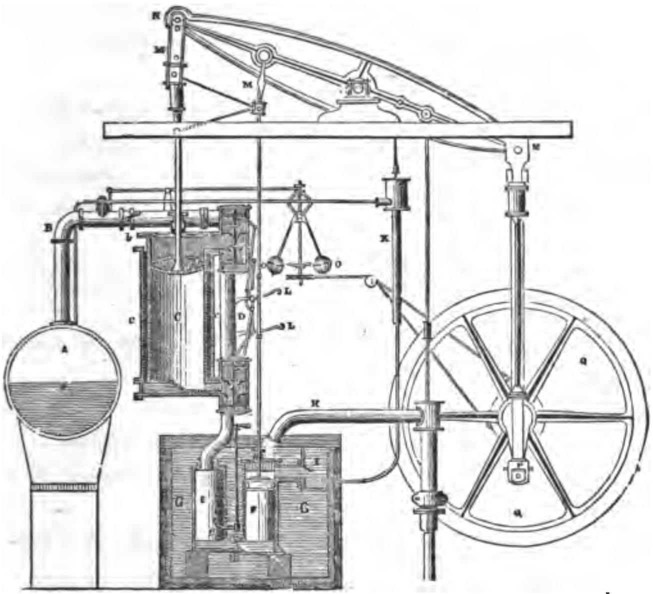
234. In all steam-engines previous to those containing the improvements made by Watt, the cold water was thrown directly into the cylinder, to condense the steam there; and Watt perceived that their sluggish action resulted from the fact that the cylinder was thus cooled at every stroke, and must again be heated by the steam (which was introduced and condensed) before there was tension enough to move the piston. His aim was to keep the cylinder at a high and uniform temperature. This he effected by condensing the steam in a *separate vessel,*

How is the condenser kept cold? Why must it be continually cooled? Describe the three pumps. How moved? How was the steam condensed before the improvements of Watt? Why was the action sluggish? How did Watt keep the cylinder hot?

by pressing the piston down by *steam* (it had before been done by the atmosphere), and by *encasing* the cylinder by another made of some poor conductor of heat.

235. *The low-pressure engine.*—The engine as above described is called *low-pressure*, because it operates by the lowest possible tension of steam, there being nothing to oppose the motion of the piston. Fig. 103 exhibits the several parts of such an engine, with the working-beam and balance-wheel which are put in motion by it.

Fig. 103.



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31 Is the engine now described *high* or *low* pressure? Why? Describe all the parts by Fig. 103.

A. The boiler.

B. The steam-pipe, conveying steam to the cylinder, having a throttle-valve at *b*.

C. The cylinder, encased by the jacket *c c*.

D. The eduction-pipe, conveying steam from both top and bottom of the cylinder to the condenser.

E. The condenser, with the jet-pipe, by which cold water is thrown in at every stroke of the piston.

F. The air-pump.

G G. The cold-water cistern.

H. The spout of the cold-water pump.

I. The hot well, containing the hot water from the condenser.

K. The hot-water pump, which returns the water from I to the boiler.

L L. Levers which open and shut the steam-valves; they are moved by pins in the piston-rod of the pump F.

M M. The parallel motion, a contrivance for communicating *straight* motion to the piston-rods of the steam cylinder and the air-pump.

N N. The working-beam, which is moved by the piston-rod of the steam-cylinder.

O O. The governor, which regulates the steam by opening and shutting the valve *b*.

P. The crank, to change the vibrating motion of the beam into the continued motion of the balance-wheel.

Q Q. The balance-wheel, for steadying the motion of the machinery.

The working-beam is often dispensed with, and the piston-rod, being kept in place by guides, is connected with the machinery by a crank. The balance-wheel is unnecessary, when

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Are the working-beam and balance-wheel always necessary?

the machinery itself furnishes sufficient momentum to steady the action; as is the case with the steamboat and the locomotive.

236. *The high-pressure engine.*—In many uses of the steam-engine, and especially in the railroad locomotive, it is better economy to allow the steam to be opposed by atmospheric pressure, thereby diminishing very much the bulk and weight of the engine. Suppose (Fig. 102) that the condenser and pump are removed, and that the valves P and Q communicate directly with the air; then when G and P are opened, the steam below the piston will be subject to atmospheric pressure, and will therefore have a tension of fifteen pounds per inch, to oppose the motion of the piston. The power of the steam which drives the piston must of course have fifteen pounds more tension than before, in order to produce the same effect. Hence, such a machine is called a *high-pressure* engine. An inspection of Fig. 103 will show how much more compact the steam-engine would become, if the condenser and all the pumps were dispensed with.

237. *Steam-valves.*—What are called *valves* in steam machinery are not strictly such, because they are not opened and shut by the pressure of the steam. They are of various constructions, but are always opened and shut at the proper moments by the machinery. A particular form of *sliding-valve* is chiefly used, called the D-valve, from its resemblance to the letter D.

The valves, which admit steam to the cylinder, are closed much before the piston is driven to the opposite end, sometimes as soon as it has moved one-third of the way; this prevents

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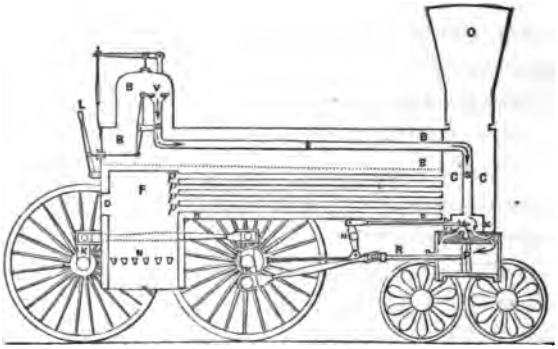
Examples. ¶ What is a *high*-pressure engine? What parts are omitted? How much more force must the steam exert? What advantage in the high pressure? Is steam admitted to the cylinder through the whole stroke? Why?

acceleration of the piston, and a violent shock at the end of the stroke, and also saves a large part of the steam.

238. *The locomotive.*—This name is given to a high-pressure engine made to transport *itself* on a railroad. It draws after it the *tender*, which contains a supply of wood and water, and then a train of cars, for the conveyance of passengers or freight. A frequent construction of the locomotive is shown in Fig. 104. F is the *furnace;* D, the door for receiving fuel; and N, the grate. The whole space B B is occupied by the *boiler.* This is traversed by a large number of metallic tubes, *p p*, open at both ends, and serving as flues to convey the flame and hot air from the furnace to the chimney C. The water should cover the tubes to the dotted line; steam fills the space above that line. The engineer, who occupies a platform in front of the furnace F, can by the lever L open or close the valve V, which is within the boiler, and admit steam to the cylinder. If the valve is opened, the steam rushes through the

Fig. 104.



What is a *locomotive?* The *tender?* Describe the parts of the engine.

pipe S S (as shown by the arrows) and enters the steam-cylinder, lying horizontally below the chimney, and drives the piston P before it, while the steam on the left of P passes into the chimney. In the valve-box X is the D-valve, which slides back and forth by the lever N. Thus the piston is impelled rapidly from end to end of the cylinder, communicating motion to the driving-wheels K K by the crank-rod R; and the rotation of the wheels, by means of friction on the rail, causes a progressive motion of the engine. That the distance advanced during each stroke of the piston may be as great as possible, the driving-wheels are made very large.

CHAPTER III.

PHENOMENA OF THE ATMOSPHERE.

239. *The height and quantity of the atmosphere.*—The total height of the atmosphere is unknown. It has been calculated that the extreme twilight is reflected by air, which is about forty-five miles high; but the atmosphere extends beyond that, probably to the height of 100 miles. The density, however, decreases so fast that *seven-eighths* of the whole is within the first ten miles.

240. Though the *height* of the air is not known, the *quantity* is known from its weight. As there rests on every square inch of the earth a weight of 14.7 lbs. (Art. 212), that is, 2,117

Where is the steam let into the air? What is the advantage of large *driving* wheels? Is the *height* of the atmosphere known? Probably how great? What change at increased heights? Is the *quantity* of air known?

lbs. on every square foot, we must multiply this number by the number of square feet on the surface of the earth, in order to obtain the weight of the entire atmosphere. The weight of air on the earth is the same as would be the weight of an ocean of mercury thirty inches deep, or an ocean of water thirty-four feet deep, covering the entire globe.

241. The height to which the air *would* extend, if its density at the earth were continued uniform to the top, is also known. The specific gravities of air and mercury are as 1 : 10440; therefore, in order that the air may press with the same weight as thirty inches of mercury, it must be 10,440 times as high, or about five miles.

242. *Decrease of density.*—Since the air would extend only *five* miles high, if undiminished in density, but does in fact rise to the height of near a ***hundred*** miles, its density must rapidly decrease upward from the earth. This decrease is in consequence of the diminished weight which rests on every successive stratum; and according to Mariotte's law (Art. 202), *the density diminishes in a geometrical ratio, while the height increases arithmetically.* Thus, as presented in the following table, the density diminishes by one-half for every three and a half miles.

Height,	0	3½	7	10½	14	17½	21	24½
Density,	1	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$

Height,	28	31½	35	38½	42	45½	49
Density,	$\frac{1}{256}$	$\frac{1}{512}$	$\frac{1}{1024}$	$\frac{1}{2048}$	$\frac{1}{4096}$	$\frac{1}{8192}$	$\frac{1}{16384}$

How is its whole *weight* found? To what is it equal? How high *would* the air extend, if as dense as at the earth? Compare the specific gravities of air and mercury. How are their heights proportioned in order to be in equilibrium? What is the law of diminished density? What increase of height diminishes density by one-half? Give a series of heights and densities.

243. If this law applied strictly, it is obvious that there would be no top, but the atmosphere would extend from the earth to an infinite distance. It does in fact, from causes which modify the law, decrease a little faster, and come to its limit at the height where the *expansive force*, which tends to raise the particles, equals the *force of gravity*, which tends to depress them.

In descending into the earth, the density would increase as fast as it decreases upward.

244. *Coldness of the upper air.*—In ascending from the earth, the air is found to grow more and more cold, till a point is reached, even in the hottest weather, where the temperature is always below the freezing point. At the equator, this height is about *three* miles, and from the equator each way it diminishes till it becomes *nothing* near the poles. The higher mountains of tropical countries reach above this limit, and are always covered with snow. Only the lower portions of the air are warm enough to sustain animal and vegetable life. The direct rays of the sun are not arrested by the air, but reach the earth and heat its surface; and the lower air is then warmed by contact with the earth. The lowest strata may indeed become so rarefied by heat as to rise and give place to colder and heavier strata above them; but they cannot ascend far, before they are so much cooled by expansion and intermingling with other air, as to find an equilibrium. In the mean time, the earth as a whole, radiates through the entire atmosphere into the space beyond, as much heat as it receives. Thus it is, that the earth

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According to this law would there be a top to the air? Is there in fact a top? Why? What change of density in descending into the earth? State the height of perpetual frost at equator; at the poles. Why are high mountains covered with snow? What part of the air is warm enough to live in? How is it warmed? How does it move after being warmed? Why not ascend to the top?

and the lower air retain about the same quantity of heat from year to year, only varying in particular places according to the season.

245. *Motion of air by heat.*—Owing to the perfect fluidity of the air, it moves with the greatest freedom whenever it is a little more rarefied by heat in one place than another. The colder and heavier air crowds up the warmer and lighter, and occupies its place.

246. *The draught of chimneys* is owing to this cause. The column of air in the flue, when once warmed more than the external air reaching to the same height, is pressed up by it. Hence there is a horizontal movement towards the fire, and an upward current in the chimney. It is by the momentum of this current that heavier substances, as smoke, and some other products of combustion, are carried up. If the fire is in a large open fireplace, the draught is not likely to be good, because so much cool air can pass into the flue. The evil will probably be remedied by lowering the breastwork of the fireplace, or substituting a stove. The interior of a flue should be smooth, especially if it is small, because gaseous substances are much more retarded in their motions than liquids are, by inequalities of surface. Other things being equal, the colder the weather, the stronger is the draught, since the external air is heavier compared with the column in the chimney. In the attempt to build a fire in a warm day, the smoke will sometimes all pour into the room, the air in the chimney being colder than that abroad.

247. The *ventilation of apartments* may often be effected on the same principle as the draught of chimneys; that is, by

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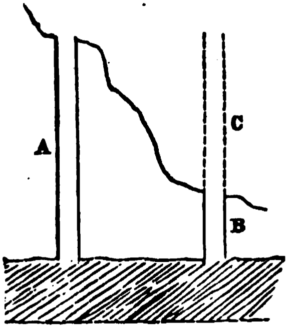
How much heat does the earth radiate in a year? Why does warmer air ascend? Explain the draught of a chimney. What motion in the room? Why is draught often bad in large fireplaces? How cured? How does weather affect draught? Why?

allowing the external air to press upward the warm and impure air of a room through suitable openings made for the purpose. Apartments warmed by close stoves need special arrangements for ventilation, much more than those warmed by open fires, since the currents which pass through an open fire may occasion all the change of air that is necessary. When there is a chimney flue in the wall of a room, with a current of hot air ascending in it, the ventilation is best accomplished by admitting the air into the flue at the upper part of the room; since it will then be removed with the velocity of the current of hot air.

Fig. 105.



248. *The ventilation of mines* is sometimes effected by shafts which open into the air at unequal elevations. Suppose A and B (Fig. 105) to be two such shafts, terminating at very different elevations on the side of a mountain. The earth remains at nearly the same temperature summer and winter, while the external air is hotter in summer and colder in winter than that within the mine. Let C be a column of the outer air above B, reaching to the same level as A. In the summer, C is *lighter* than air within the earth; hence, B and C are lighter than A, and the current is down the long shaft, and up the short one. In the winter, C being more dense than the internal air, B and C are heavier than A, and the current is reversed. In spring and

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State how a room may be ventilated. How, if a hot-air flue passes near it? The shafts of a mine, how made to favor ventilation? Which way is the circulation in winter? In summer? Explain.

autumn, when the columns are of about equal density, the miners complain of the suffocating state of the air. When there is no opportunity of ventilating a mine in this manner, a fire is sometimes kept burning under one of the shafts.

249. *Winds.*—The unequal pressure of air caused by heat is also the cause of *winds.* At the place of greatest rarefaction by heat, the motion is *upward*, while air comes in *horizontally* to occupy the same place. The latter motion is usually the only one perceived.

250. *Land and sea breezes.*—The sea-breeze by day is a fact of common observation on most sea-coasts. The surface of land becomes more heated by the sun than the surface of water. Hence the air over the land, being heated by it, is crowded up by the cooler air which lies on the water. This horizontal motion of the cooler air from the water to the land is called a sea-breeze. As land absorbs heat by day more rapidly than water does, so it radiates it faster by night; hence, the air on the land, becoming colder than that on the water, flows off from the shore, and constitutes the *land-breeze* of the night.

251. *The trade-winds.*—These are the regular currents which set in toward the equator from both sides, crowding up the heated air of the torrid zone. On the north of the equator, the trade-winds are generally from the northeast, on the south side, from the southeast. These would be respectively a north and a south wind, were it not for the rotation of the earth on its axis. The earth revolves toward the east; and the air, which leaves a higher latitude, has only so much velocity east-

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What is the cause of winds? *Which* motion is perceived as wind? Explain the *sea-breeze.* The *land-breeze.* What are the trade-winds? In what direction north of the equator? South of it?

ward as the parallel from which it comes; hence, as it approaches the equator, it passes over land which has a swifter eastward motion, so that, *relatively* to the earth, the air has a motion *from* the east combined with its motion from the north, and the resultant of the two motions is a *northeast* wind. In a similar manner is explained the *southeast* wind prevailing so generally near the southern tropic. In certain localities the wind blows from a northerly quarter for six months, and then six months from a southern one, alternating with the sun as he passes back and forth across the equator. The *monsoons* of southern Asia are a remarkable example.

252. The air which rises up from the torrid zone, flows away toward the poles to restore the equilibrium; and as these returning currents have the velocity of the equator, they will have more eastward motion than the parallels which they reach, and thus will be *relatively southwest* winds in the northern hemisphere, and *northwest* winds in the southern hemisphere. The highest kind of clouds (the *cirrus*) usually indicate these directions.

253. The winds of the temperate zones are very fluctuating, owing to various local and irregular causes, such as coast lines, mountain ranges, unequal distribution of sunshine by clouds, &c. On the higher parallels of these zones, the influence of the upper currents, which flow from the equator, is considerably felt, occasioning a general prevalence of winds from westerly quarters.

254. *Revolving winds.*—Winds often circulate around a

Why is there motion from the *east* in each case? What are the monsoons? What becomes of the air which ascends from the equator? Why does it acquire a motion from the west? What is the character of the winds of the temperate zones? What is the prevailing direction? Name an example of revolving winds.

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vertical axis. The *northeast storms* of the American Atlantic coast are examples of revolving winds on a large scale. The diameter of the storm is from 200 to 500 miles, lying partly on the land and partly on the water, and the whole whirling mass advances along the border of the West India Islands, and thence along the shore of the mainland till it is lost in the northern Atlantic ocean. The winds of these storms always revolve from right to left. Small and violent tornadoes are usually of a whirling character.

255. *Velocity and force of winds.*—Wind moving at the rate of two or three miles per hour is hardly noticeable; a velocity of twelve miles makes a strong breeze; forty miles, a high wind; 100 miles, a destructive hurricane. The force of wind varies as the *square* of the velocity, because quantity and velocity increase alike, and are both concerned in estimating the force. Hence, *twice* the velocity causes *four* times the force; and ten times the velocity, 100 times the force. The force of wind is estimated at half a pound on a square foot when the velocity is ten miles per hour. Therefore, at 100 miles per hour, the force would be fifty lbs. on a square foot.

256. *Vapor of the atmosphere.*—By the heat of the sun all the waters of the earth form above them an atmosphere of vapor or invisible moisture. Even ice and snow, at the lowest temperatures, throw off some vapor. This vapor can *exist* in just as great quantities in the air as in a vacuum; but there is not likely to be as much, since it is not so rapidly formed, be-

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What is the diameter of Atlantic coast storms? Revolve which way? What is the motion of air in tornadoes? State the velocity of a wind scarcely perceptible. Of a strong breeze. A high wind. A destructive hurricane. How does the *force* vary? Illustrate. What is always mingled with the air? Can as much vapor exist in air as in a vacuum? Is there *likely* to be as much? Why?

cause the air *obstructs* its movements, and thus retards its formation. The quantity of moisture which can exist at any one time depends on the temperature. The quantity is measured, as the quantity of air is, by the height to which it will sustain a column of mercury. When the temperature is 80°, an atmosphere of moisture (as much as could exist) would be called 1, because it would sustain *one inch* of mercury; at the freezing point it is 0.18; at *zero*, only 0.04. The weight of a full atmosphere of moisture is doubled by every rise of 12° or 14°, in the coldest weather; every 21° or 22° in the warmest. The *quantity* or *weight* of moisture is commonly expressed by the word *tension*, because the tension varies as the weight which is the compressing force (Art. 202).

257. The *humidity* or dampness of the air depends not merely on the amount of moisture, but on the temperature. In a high temperature a great deal more moisture is required than in a low one, to render the air equally damp. In summer there is much more moisture in the air than in winter, but yet the air is not so damp. So, the humidity of *night* is generally greater than that of *day*, and yet the quantity of moisture may be the same, or even less. At zero, if the air is as damp as possible, there is only 0.04 of moisture; but at 80°, there is 1.0 of moisture, and yet the humidity is the same. Humidity is expressed by 100, and numbers less than 100. If there is as great a quantity of moisture as possible, the humidity, whatever the temperature may be, is called 100; if at any temperature

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How is the quantity of vapor measured? What rise of temperature doubles the possible amount of moisture in summer? In winter? What word is used for the amount? What does the humidity depend on? Can there be more humidity, and yet less quantity or tension? Compare summer and winter. Day and night. How is humidity expressed? What does 100 express?

there is half as much as could possibly exist, the humidity is *fifty;* and if only one-fifth as much, it is *twenty*, &c. The instrument now principally used for determining the tension and humidity, is called the *psychrometer.*

258. *The dew-point.*—If the temperature is lowered until the humidity is 100, then it cannot fall any lower without *precipitating* some of the moisture from the invisible gaseous form, into the liquid or solid form. This point of temperature, at which precipitation begins, is called the *dew-point.* When a tumbler of cold water is brought into warm air, it often has moisture collected on its outside; the surface of the tumbler is then below the dew-point. Place a thermometer in the water, and wipe the moisture from the tumbler as often as it forms, until it ceases to appear; at that moment, the thermometer in the water gives the dew-point; and by comparing it with a thermometer in the air, it may be seen how much the dew-point is below the actual temperature. If the moisture should not cease to collect on the tumbler till the water had become as warm as the air, it would indicate that the humidity is 100.

259. *Precipitations of moisture.*—The air may be cooled below the dew-point under many different circumstances, and hence there are many forms of precipitation of moisture. The following names are given to them: *dew*, *frost*, *fog*, *cloud*, *rain*, *mist*, *hail*, *sleet*, and *snow.*

260. *Dew.*—This form of the deposition of moisture occurs on the surfaces of bodies which are so cold as to cool the adjacent air below the dew-point. Dew does not *fall*, but is left on bodies by the air in contact with them. As bodies at night

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Fifty, &c.? The instrument for observing humidity and tension. Define the dew-point. Illustrate by tumbler of cold water. What does the humidity of 100 indicate? When is moisture precipitated? State the forms of precipitation. What is dew? Does it fall?

grow cold by radiation, the air which touches them is cooled also; and as soon as it reaches the dew-point, it begins to deposit minute drops of water, which grow larger as the process goes on.

261. In the same situation, those receive most dew which are the best radiators. Vegetable leaves are good radiators, and receive much dew. Polished metals radiate little, and have little dew upon them.

Among equally good radiators, those have most dew which are most detached from good conductors of heat. Leaves on their slender stems derive very little heat from the earth, and have more dew on that account. Gravel and sand radiate well, but receive only little dew, because they are kept warm by heat conducted from the mass below.

262. The same substances have more dew on them, according as they are more exposed to the open sky. Other objects radiate heat back again, but what is radiated into the pure sky is never returned. Hence there is less dew among trees and buildings, and in cloudy nights.

Wind often prevents dew, by not allowing the air to remain long enough in contact with bodies to be cooled by them.

263. *Frost.*—When the radiating body is cooled below the freezing-point, the moisture is deposited in solid crystals, called frost. Frost will often be found on the best radiators, or those most exposed to the open sky, when only dew is found elsewhere.

264. *Fog.*—This form of precipitation consists of minute globules of water sustained in the air near the earth. It is most

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55 What bodies receive most dew? Compare leaves and polished metals. Compare leaves and sand. The effect of buildings, trees, clouds, wind? 56 When does dew become frost? 57 When does the deposited moisture take the form of fog?

likely to occur near water, where the dew-point is high, and where cold air has the opportunity to mix with it. The mixing of masses of air of different temperatures is very likely to cause moisture to be deposited; and is sure to do it, if their humidity is at a high point, and their temperatures widely different. Thus, the moisture of our breath is condensed into a visible form when the air is very cold; and the steam of a locomotive is poured out in a dense cloud, either when the air is quite cold, or, if warm, when it is very damp. The fogs of the Newfoundland banks are formed by the mixing of the warm and humid air of the Gulf stream with the cold air of that northern coast.

265. *Cloud.*—The same as fog, except at a greater elevation. Its formation is supposed to be due, often, to the mixing of currents of different temperatures, and in other cases to the fact that air, ascending from the earth, becomes cooled by *expansion* below its dew-point. Clouds are frequently higher than the limit of perpetual frost; then, even in the hottest season, they consist of snow crystals.

The following is the usual classification of clouds:

1. *Cirrus.*—(Fig. 106, *c.*) This cloud has a fibrous structure, like *hair* or flax, straight or bent; and frequently is gathered, at one end, into a confused heap of fibres. It is the highest kind of cloud, and often frozen.

2. *Cumulus.*—(Fig. 106, *a.*) This consists of compact rounded *heaps*, often like the summits of mountains covered with snow. They are nearly confined to the summer season, and

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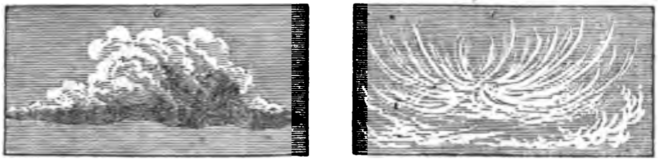
What does fog consist of? When does the steam of the locomotive become visible? Cause of fog on the banks of Newfoundland? Difference between fog and cloud? In what two ways may cloud be formed? Clouds above the freezing limit consist of what? Describe the different kinds of cloud.

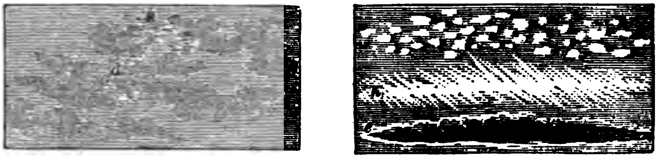
the daytime. It is said they do not occur far out at sea. This kind is not usually so high as the cirrus; and appears, more than any other cloud, to be formed directly by rising columns, which are so cooled by expansion as to fall below the dew-point.

Fig. 106.



Cumulus. *Cirrus.*

Fig. 107.



Stratus and Nimbus. *Compound Clouds.*

3. *Stratus.*—(Fig. 107, *b.*) *Sheets* or stripes of cloud, sometimes overspreading the whole sky, or as a fog, covering the surface of the earth or water.

4. *Cirro-cumulus.*—(Fig. 107, *n.*) Fleecy patches of cloud, sometimes called *mackerel* sky.

5. *Cirro-stratus.*—(Fig. 107, *h.*) The stratus, with something of the fibrous structure.

6. *Cumulo-stratus.*—(Fig. 107 *e.*) The stratus, with partially developed cumulus forms.

Which kind are formed only in summer, daytime, and on land?

7. *Nimbus.*—Any cloud receives this name when it is formed so rapidly as to fall in rain, hail, or snow.

266. *Rain.*—Whether the precipitated moisture has the form of cloud or rain, depends on the rapidity with which precipitation takes place. If all the circumstances are favorable, the vapor may be condensed so rapidly that the minute globules touch each other, forming drops which cannot be sustained in the air. It must be remembered that globules of fog or cloud are as heavy specifically as drops of rain. But they have so much more surface in comparison with their weight, that they are kept up by the slightest motions. For a similar reason, the *dust* of minerals, twice as heavy as water, is long sustained in air which is in motion, while sand or gravel of the same materials falls at once.

Mist is fine rain, the drops of which are barely large enough to fall slowly to the earth. *Sleet* is frozen mist.

267. *Hail.*—When the air, in which rapid condensation is taking place, is so cold as to freeze the drops, hail is formed. Hailstones are rarely spherical, perhaps because they continue to receive accretions of ice as they fall. Hail-storms are most frequent in the mountainous regions of the temperate zones, where there is most frequent opportunity for a mingling of the heated air of the valleys with the air of freezing temperature at the height of the mountain tops.

268. *Snow* consists of the minute crystals of frozen cloud, united in flakes. Like all transparent substances, when in a state of minute division, it owes its whiteness to innumerable reflecting surfaces. A cloud, when the sun shines upon it, is

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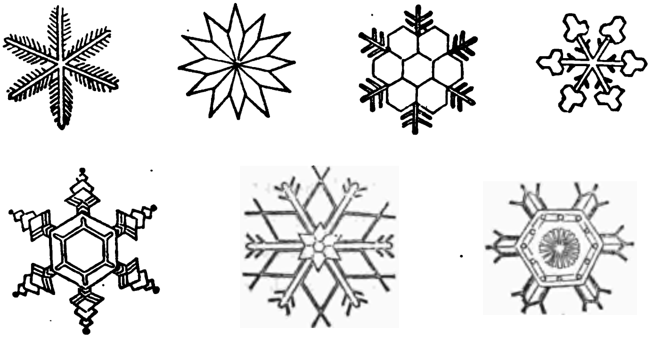
What decides whether the moisture shall form cloud or rain? How is cloud held up? How is dust sustained? Why are not drops and gravel-stones held up by the air? Define mist. Sleet. Hail. Reason for irregularity in hailstones. What does snow consist of? Why is it white?

for the same reason intensely white. Fig. 108 shows a few of the forms of elementary crystals in snow-flakes.

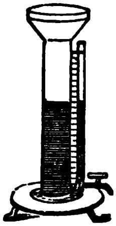
Fig. 108.



269. *Meteorological journal.*—In order to keep a meteorological journal, the instruments needed are the following:—

A *thermometer*, in the external air, for temperature.

Fig. 109.



A *barometer*, with attached thermometer, for finding the pressure of the atmosphere.

A *psychrometer*, for the tension of vapor and humidity.

A *rain-gauge.*—(Fig. 109.) The depth of rain which falls in a single shower is often so small a fraction of an inch, that for accurate determination the depth needs to be multiplied. If, for example, the section of the tube is *one-tenth* of the open area at the top, then the water in the tube will be *ten* times the true depth. Hence, after measuring the depth in

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What instruments are used for keeping a meteorological journal? State how rain is measured?

hundredths of an inch, call them so many *thousandths*, and this will be the true depth.

270. *Printed tables* are used in company with the psychrometer, for ascertaining the tension and humidity, from the readings of the dry bulb and wet bulb of the instrument; also with the barometer, in order to correct for expansion of mercury by heat.

THE MOTION OF CURRENTS IN FLUIDS.

271. There are certain phenomena attending the flow of currents through a fluid, which are common to hydraulics and pneumatics; they are briefly described in this connection.

272. *Motion communicated to the surrounding fluid.*—If a stream is driven through a medium, it carries along adjoining particles by *friction* or *adhesion*. Suppose that in a vessel of water there is a plane gently inclined, reaching to the edge of the vessel; and that a stream of water, brought from a higher level, is driven up this plane with sufficient force to pass over the top; it will take along continually some part of the surrounding water, until the vessel is emptied to the lowest part of the stream. A stream of air, in like manner, blown through the air, carries the adjacent particles with it. A stream of water through the air also conveys air with it, as may be seen whenever water is poured from a pitcher into a vessel containing water; bubbles of air in great numbers are carried down beneath the surface. A cascade falling into deep water drives immense quantities of air with it, which presently rises as foam on the surface. The current of air, rushing from behind the

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For what purpose are printed tables needed? What effect is produced by a stream through a medium? Describe the experiment with water. Pouring water into water. Cascade. Why does air rush out from behind a waterfall?

foot of a waterfall, is brought down by the back side of the sheet, and is supplied constantly by air which passes behind near the top of the fall.

273. *Draught of chimneys.*—If a stream of air passes across the end of a tube, the air within the tube is liable to be carried with the stream, and thus a partial vacuum formed in the tube. It is thus that wind over a chimney rarefies the air within, and increases the draught. Tubes extending up into the air from the top of public halls, and the holds of ships, may, on the same principle, aid in their ventilation.

274. *A stream meeting a surface.*—When a fluid meets a solid body, instead of rebounding, it tends to follow the surface, and will almost invariably do so, except when the surface changes its direction too suddenly. This effect is partly due to adhesion, and partly to the resistance of the medium in which the stream moves.

275. *Diminished pressure on the surface.*—When a stream thus flows along a surface, the pressure of the medium against the surface is slightly diminished. If a piece of tin be curved like the letter S, and delicately suspended by the middle of its edge, and a stream blown obliquely against its convex side, instead of turning *away* from the stream, it moves *towards* it; and by repeating the blast at every half revolution, it may be made to whirl rapidly.

276. The *pneumatic paradox* is explained on the same principle. A disk of pasteboard being placed on another, and a stream of air being blown against it through a hole in the latter, it cannot be blown off. The stream flows out in all directions

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The effect of a stream across the end of a tube? Illustrate by draught. When a stream meets a surface, how does it tend to move? Why? What effect is produced on the surface? Describe experiment with curved vane? Describe pneumatic paradox. Explain.

from between the disks, and diminishes the atmospheric pressure on the inner surface.

277. *Formation of vortices.*—When a stream leaves a surface on account of too abrupt a curvature, a whirling motion is likely to occur in the medium back of the edge. Thus, vortices are formed in water, where its motion is arrested by rocks; the whirl may have its origin at some depth in the water, and the motion be communicated to the top.

278. The surface is hollow in the center of a vortex, because of centrifugal force. When the rotation is very swift, a tube is sometimes formed, in which the air descends to great depths. These are called *whirlpools*, and arise, as is supposed, from deep currents, obstructed in their motion among rocks. The wind, in passing off from the side of a building, causes interrupted eddies behind on the leeward side, as may be seen by the motions of leaves or other light substances.

279. Vortices frequently arise also from the partial counteraction of two currents. Thus *whirlwinds* are produced in air, and travel over the surface of the earth. The rarefaction in the center, produced by centrifugal force, causes light substances to rise, and clouds to descend. These whirls are called *water-spouts* when they pass over water, and cause the spray to rise in their axes.

When do streams tend to produce vortices? Form of the surface? How are they formed in deep water, and are called by what name? How are whirlwinds produced? When are they called water-spouts?

PART IV.—ACOUSTICS.

CHAPTER I.

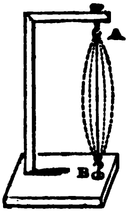
THE PRODUCTION AND PROPAGATION OF SOUND.

280. *Acoustics* is the science which treats of the nature and laws of sound.

Sound is the *vibratory motion* in a medium, which, on reaching the ear, causes hearing. The word *sound* is also used to denote the *impression* which the vibrations produce on the ear.

281. By careful observations it is ascertained that *vibrations* in the surrounding medium are essential to hearing; and these vibrations can always be traced to the body in which the sound originates. A body becomes a source of sound by producing impulses on the medium, which are conveyed in waves to the organ of hearing. In many cases of prolonged sound, it may be perceived that these impulses are made by vibrations in the body itself. Thus, if a string (Fig. 110) be stretched between A and B, and then pulled aside, its motions back and forth are visible, so long as the sound emitted by it is heard. When a tumbler of water is made to ring, the surface

Fig. 110.



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1 Of what does acoustics treat? 2 What is sound? What causes it? Mention cases in which the vibrations can be seen.

of the water is thrown into a beautiful system of waves. If sand be scattered on a horizontal plate, while sound is produced by drawing a bow across its edge, the sand will dance over its surface till it rests on certain lines which do not vibrate.

282. *Sonorous* bodies are such as are fitted by their *elasticity* and their *favorable form* to be thrown into a state of vibration. Inelastic substances, like lead, are not sonorous. Nor are those which have very solid and compact forms, as the cube or the sphere. Thin plates and slender rods of elastic material, are peculiarly fitted for producing continued sound.

283. *Medium of sound.*—There must be not only a vibrating body, as a *source* of sound, but a medium for its *communication* to the ear. The common medium is air. If a bell be rung in the vacuum of an exhausted receiver, it cannot be heard. And during the process of exhaustion, the sound becomes more and more feeble till it ceases, showing that the intensity or loudness of sound diminishes with the density of the air. So, also, on high mountains, all sounds seem feeble on account of the rarity of the air. On the contrary, sounds grow louder as the density is increased. In a diving-bell sunk to a considerable depth, even a whisper is painfully loud.

284. *Velocity in air.*—Sound occupies a perceptible time in passing through air. The flash of a distant gun is seen before the report is heard. Thunder usually follows lightning after an interval of several seconds. If a person is sawing or hammering at a distance, the perceptions of the strokes received

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4 What two things are essential to render a body sonorous? Why is not lead sonorous? What *forms* are not sonorous? What are most favorable? 5 What is the usual medium of sound? Experiment to prove that a medium is necessary? Sounds on a mountain, why faint? Why loud in a diving-bell at great depths? Show that sound requires *time* to travel a distance. Gun. Lightning.

by the eye and the ear do not generally agree with each other.

285. From many careful experiments, made for the purpose of determining the velocity of sound, it is ascertained that it travels at the rate of 1090 feet per second, at the temperature of 32°, the freezing-point. If the air is warmer, sound moves faster, and if colder, it moves slower, by nearly *one foot* in a second for every degree. It therefore travels about 100 feet per second faster in our hottest weather, than it does in our coldest. If the wind blows in the same direction with the sound, its velocity is added to that ot the sound, and subtracted, if in the opposite direction. This, however, makes but little difference, since sound moves 50 or 100 times faster than winds of ordinary velocity.

286. Besides temperature and wind, other circumstances do not affect the velocity of sound. Whether the air is light or heavy, moist or dry, the rate is the same. If snow is falling, it prevents sound from going as far, and renders it more feeble at a given distance, but it does not diminish its velocity. And all *kinds* of sounds,—the report of a gun,—the blow of a hammer,—and the notes of a musical instrument, whether high or low, soft or loud, move at the same rate. That high and low notes in music advance with the same velocity, has been proved by causing familiar tunes to be played on a flute at one end of a tube more than half a mile long, and listened to at the other end. No derangement in the succession of high and low notes takes place, as would be the case if they moved with different velocities.

287. *Diffusion of sound.*—Sound is usually more loud, and

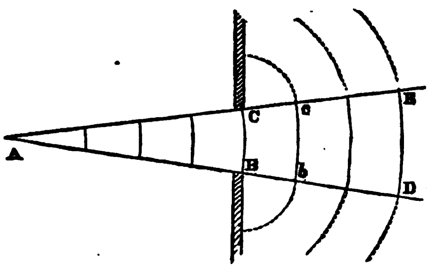
What is the velocity of *sound?* What allowance for heat and cold? For wind? For weight or moisture? State in regard to different *kinds* of sound, and sounds of different pitch. How is the last proved?

is heard at a greater distance in the direction of the first impulse, than in others. For instance, a cannon is heard furthest in the direction in which it is fired. And a public speaker in the open air, is heard more than three times as far by those in front, as he is by those behind him.

288. If sound is prevented from spreading in certain directions, it proceeds further in other directions. Hence it is, that in a column of air, confined in a tube, sound is conveyed to a great distance. The music of a flute has been distinctly heard more than half a mile, by being conducted along the air in an aqueduct pipe. Speaking-tubes are of great service for carrying messages and orders to all parts of large edifices.

289. When sound passes through an opening, it is not entirely confined within the straight lines drawn from the source along the edges of the opening; but spreads laterally in some degree. Thus (Fig. 111), if sound originates at A, and passes through the opening B C, a person anywhere between B D, and C E, will hear the full sound, but the moment he steps outside of either line, he will perceive the sound to be weakened, but not destroyed. It is diffused imperfectly beyond those lines, as though emanating from B and C, as centers.

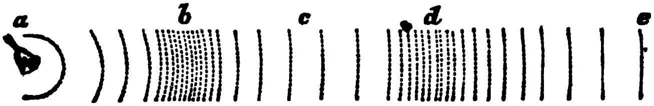
Fig. 111.



Is sound heard equally well in all *directions?* A gun? A public speaker? State the effect of a tube? Use of speaking-tubes? Is sound limited within straight lines, in going through an opening? Illustrate by figure.

290. *Nature of acoustic waves.*—In water-waves, it has been stated (Art. 197), that the *particles* of water rise and fall, while the *waves*, which consist of those particles, move horizontally along the surface of the water. The vibrations of the particles are *transverse* to the direction of the wave motion. In the progress of sound, it is different; the vibrations are *longitudinal*, that is, the particles oscillate back and forth in the line of wave motion. Hence, the waves are not waves of *ridges* and *hollows*, but waves of *condensations* and *rarefactions*. Fig. 112 will give an idea of the condition of the air, when thrown into oscillation around a center. At *b* and *d* the air is condensed; at *a*, *c*, and *e*, it is rarefied. The particles from the center to *b*, have been crowded forward, so as to produce condensation at *b*. Those at *b* are pressed forward against those still more distant, so that the state of condensation is carried onward. But there is a rarefaction, resulting from the condensation; for the increased density at *b*, causes the particles, that have crowded toward that point, to rebound, while those in advance of them move forward. Thus, the particles at any place separate at one moment as much as they crowded upon each other the moment before. These successive states of condensation and rarefaction spread outward from the source in all directions, with the velocity

Fig. 112.



In water-waves, state how the particles move. Are the vibrations of air *transverse* or *longitudinal*? Explain the meaning of this. Which kind produces condensation and rarefaction? Show by the figure how the particles move.

of about 1,100 feet per second. But while the *waves* are thus swiftly advancing, the *particles* which compose the waves merely vibrate back and forth in the same line in which the wave moves. Since the waves proceed outward, with equal velocity in all directions, the *form* of each is that of a spherical surface, whose center is the source of sound.

291. *Other media than air.*—Sound is conveyed by all elastic substances, whether gaseous, liquid, or solid; and the nature of the waves is the same in all. The chief difference consists in the velocity with which the waves travel in different media.

292. It is readily proved that all *gases* and *vapors* conduct sound, by removing the air from a receiver which has a bell in it, till the ringing of the bell ceases to be heard, and then filling the receiver with any gaseous substance whatever; the sound of the bell is again heard.

293. *Liquids* are good conductors of sound; for a bell rung under water can be heard at a great distance in the water. In 1826, Colladon made many careful experiments in the water of Lake Geneva. He found that the sound would not leave the water, so as to be heard in the air, except nearly over the bell. But by pressing down a tin tube into the water, the sound, striking the side of the tube at right angles, would enter the air within it, and be heard at a distance nearly as well as by placing the ear under water. In this way he ascertained, that when the temperature of water is 47°, sound moves in it at the rate of 4,700 feet per second, which is more than four times as fast as in air. He observed also that sound in water does not pass around the edges of bodies, except in a

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What is the form of the waves? What substances besides air convey sound? How is it proved that gases and vapors convey it? Describe Colladon's experiments on sound in water. What is the velocity?

very slight degree. If, in Fig. 111, A represents the source of sound, and B C an opening between rocks under water, the sound, after passing B C, is limited by the straight lines A D, A E, and cannot be heard behind the rocks, as it could be, if the experiment were performed in the air. Sound in water, therefore, has a strong analogy to light, in casting a sort of shadow; it is sometimes called an *acoustic shadow.*

294. Elastic *solid* bodies are excellent media of sound. If the ear be held close to one end of a long iron rod, even the scratch of a pin, made at the other end of the rod, will be distinctly heard, the sound being communicated by the iron. A similar experiment may be tried on a long stick of timber. If the ears be stopped, and the end of a long wire be held between the teeth, a slight scratch or blow on the remote end will be heard as a very loud sound. In this case the wire and the bones of the head convey the sound more perfectly than the air can ever do. The sound of earthquakes and volcanic eruptions is transmitted to great distances through the solid earth. It has been ascertained by experiments on cast iron, that sound travels in that material about 11,000 feet in a second, that is, about *ten* times as fast as in the air.

295. *Change from one medium to another.*—It is observed that sounds pass very imperfectly from water into air, and also from air into water. So, if the bell of the air-pump experiment (Art. 283), while ringing, be shut up in the receiver, the sound is feeble even before any air is removed, simply on account of the glass between the bell and the ear. Yet glass is an excellent

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What is an *acoustic* shadow? Explain by figure. Sound in an iron rod? Describe experiment with wire held by the teeth. Refer to earthquakes. The velocity of sound in iron? How is sound affected in passing from one medium to another? Example in the receiver of the air-pump. Is glass a good or a poor conductor of sound?

conductor of sound, and therefore it is inferred that sound is obstructed in going from one medium to another. Hence it is, that sounds are feebly heard on the opposite side of an object, even when that object is a good conductor of sound. If the intervening body is divided up into a number of thicknesses, so that the sound has to pass several times from one substance to another, it can scarcely be heard at all. This explains the fact, that a tumbler, which rings clearly when filled with a liquid, will have its sound entirely deadened, if the liquid is covered with foam, which consists of many alternations of liquid and air. So several thicknesses of cloth of a loose texture are almost entirely impervious to sound.

296. *Reflection of sound.*—When a system of sound-waves meets a surface, it is reflected back into the air, according to the law, that *the angle of reflection equals the angle of incidence.* A reflected sound is called an *echo.* In accordance with the law just named, if a person would hear the echo of his own voice, he must place himself in a line which is perpendicular to the echoing surface. Buildings, groves, rocks, mountains, and clouds, are the usual echoing bodies. Echoes in some situations are very much multiplied by the number and varied distances of the reflecting surfaces, or by the repetition of echoes between parallel surfaces. Thus, when a cannon is fired in a valley among abrupt mountains, the reverberation lasts sometimes for minutes. Two parallel walls of a building have been known to repeat the echo of a pistol between fifty and sixty times. The clouds cause echoes, as may be proved by observing the sound of a cannon under a clear, and then under a cloudy sky; in the

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Foaming liquid in a tumbler, explain the effect. State the *law* of reflection of sound. Define *echo.* How can one hear the echo of his own voice? What surfaces cause echoes? How are multiplied echoes produced? Cannon among mountains? Gun fired in a clear or a cloudy day?

former case, the report is single and sharp; in the latter, it is prolonged and reverberated, by repeated reflections between the clouds and the earth. The reverberations of thunder are in a great degree, but not altogether, caused in the same way.

297. When a body produces a single and distinct echo, its distance may be found by noticing how many seconds intervene between the original sound and its echo, and multiplying one-half that number by 1,130, which is the velocity of sound in ordinary summer weather.

298. *Concentrated echoes.*—It is a direct consequence of the law of reflection, that *concave* surfaces will ordinarily collect the echoes, and thus render the sound more intense. If sound is emitted from the center of a hollow sphere, all the echoes will be returned again to the center, because every line of sound strikes the surface perpendicularly. If two mirrors are prepared in the form of concave paraboloids, and placed exactly facing each other, at any distance whatever, a sound produced in the focus of one will be reflected to the other in parallel lines, and thence conveyed to the focus of the second, exactly as heat or light would be. For the same law governs them all. It is often noticed that concave walls, such as niches, domes, &c., concentrate sounds into some point in front of them. If a concave shell is held to the ear, a peculiar murmur is heard, which is a concentration into the ear of the various slight sounds that are passing through the air, and ordinarily attract no attention. The concave surfaces of *speaking-trumpets*, and of *ear-trumpets*, are perhaps partly concerned in the increase of sound, by reflecting several lines of sound into one axis; but a

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Explain the reverberations of thunder. How is the *distance* of an echoing surface found? What surfaces *concentrate* echoes? Example of hollow sphere? Two mirrors? Shell? Explain the action of speaking-trumpets, and ear-trumpets.

part of their effect is supposed to be owing to the action of the tube in limiting, and thus intensifying the sound in one direction (Art. 288).

299. Concave surfaces cause the curious effects of what are called *whispering-galleries.* In many of these instances, however, there seems to be a continued series of reflections from point to point, along the smooth concave wall, which all meet simultaneously at the opposite side of the dome; for the whisperer places his lips, and the hearer his ear, close to the surface, and not in the focus of the curve. The dome of St. Paul's in London is an example of this kind. The interior is about one hundred feet across; and yet a whisper, which could not be heard ten feet in the open air, if uttered close to the wall on one side, is distinctly heard at the side opposite.

300. *Resonance of rooms.*—If a room has smooth, hard walls, and is unfurnished, its reverberations will be loud and long continued. Stamp on the floor, or make any other sudden noise, and its echoes, passing back and forth, will cause a prolonged musical note, whose pitch will be lower, as the apartment is larger. This is called the *resonance* of the room. But the introduction of furniture, especially carpet, curtains, and all soft, yielding substances, will nearly destroy this effect. An empty room is distinguished from one which is furnished, or a small room from a large one, as readily by the ear as by the eye.

301. In halls for public speaking, echoes may be favorable, or they may be injurious, according to the relation of the echoing surfaces to the speaker. When an echo comes to the ear within about *one-sixteenth* of a second after the principal sound,

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Whispering-galleries? How is a whisper heard at a distance in St. Paul's Church? What is the *resonance* of a room? What condition of the room will give *prolonged* sound? Effect of furniture? Are echoes always injurious in a public hall? When, and when not?

it will blend with it sufficiently to seem a part of it; and then the echo is *advantageous*, by strengthening each syllable as it is uttered. The echo will follow the original sound thus closely, whenever the wall which reflects it is within thirty or forty feet of the speaker. If much more distant than this, the echo will be sensibly later than the direct sound, and tend to produce confusion. Hard, smooth surfaces, provided they are not more than thirty-five feet from the speaker, and provided also they are not concave, so as to concentrate sound to particular points, instead of diffusing it, tend to strengthen the sound of his voice, without causing confusion in the succession of syllables. Echoes from surfaces at a greater distance than this, should be prevented as much as possible, by breaking up and interrupting the surfaces, or in some way destroying their reflective power.

CHAPTER II.

NATURE AND RELATIONS OF MUSICAL SOUNDS.

302. *Musical sounds.*—Whenever the vibrations which reach the ear, are more frequent than fifteen or twenty per second, and are perfectly *equidistant* from each other, we call the sound musical. It is immaterial what causes the impulses on the air, if they are only *isochronous* (that is, at a uniform rate per second), then the effect is a musical tone. Not only the vibrations of an elastic plate of metal, and those of a stretched cord, but the strokes of the teeth of a wheel against a stick,

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How near the speaker should good echoing surfaces be? Why? That a sound may be *musical*, what must be true of the vibrations? Give examples.

and the echoes from the blow of a hammer in an empty room, cause sounds which are musical.

The *pitch* of a musical note is its degree of acuteness, and is dependent entirely on the *rate* of vibration. The greater the number of vibrations per second, the more acute the sound, in other words, the higher the pitch.

303. *The monochord.*—If a smooth compact string be stretched over bridges on the ends of a box, made of thin wood, it will emit a musical sound, when it is caused to vibrate; and many facts respecting such sounds are ascertained by this simple piece of apparatus, called the *monochord.* In the first place it is observed, that though the *loudness* of the sound is altered by the extent to which it vibrates from side to side, yet the *pitch* is not changed. Hence, if made to vibrate violently at first, and then left to diminish the extent of its motion, the sound grows gradually more and more feeble till it stops, but the same pitch is maintained throughout.

304. The tension of the monochord is measured by weights hung upon one end which passes over a pulley. The pitch is found to depend on three things,—the *length* of the string, its *weight* per inch, and its *tension.* It is observed, that the greater the length, or the greater the weight, the *lower* the pitch; but the greater the tension, the *higher* the pitch. Therefore, a string vibrates more slowly, when it is longer, or when it is heavier, or when it is less strained. The strings of viols are of different *weights*, in order to give different tones; and in playing, the performer alters the length of each one as

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What does *pitch* depend on? State the connection between pitch, and rate of vibration. Describe the monochord. If the *extent* of vibration is altered, what change in the sound? Is the pitch affected? How is the tension altered? On how many and what particulars does pitch depend? State how the pitch is affected by changes in each. Illustrate by the viol. Also by the piano.

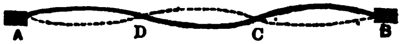
much as he pleases; and thus the instrument furnishes a great variety of notes. In tuning, he adjusts each string by varying the tension, so that it shall give the exact tone required. In the piano, the strings are of various lengths and weights, and they are tuned by altering the tension.

305. *The musical scale.*—When the weight and tension remain the same, the *number of vibrations varies inversely as the length.* *One-half* the length vibrates *twice as often*, and *one-third* of it, *three times* as often, as the whole. The common scale of musical sounds is obtained from the monochord, by dividing it in the following manner. The sound of the whole string being the first, or *fundamental* sound, the several sounds of the scale are given by these fractions, namely, 1, $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, $\frac{1}{2}$. If a string were strained, and then divided in this manner, any one would perceive that the succession of sounds is the same as that which is used in music. From these fractions is readily obtained the relative *number* of vibrations in the several sounds of the musical scale, according to the law mentioned above. Thus two-thirds of the string, which gives the *fifth* note of the scale, makes *three* vibrations, while the whole makes *two;* and one-half the string, which gives the *eighth* note, or the *octave*, makes *twice* as many vibrations as the whole in the same time.

306. *Vibration in parts.*—In making a string vibrate, it is often noticed that more than one sound is produced; and by varying the action of the bow upon the string, a number of different sounds may be obtained, and sometimes even two or three at the same time. These are called *harmonic* sounds, and are produced by vibrations of the string in *parts.* Thus, if A B

State the *law* of vibration as to *length*, and give examples. What is the *fundamental* sound? State the *parts* of the whole, for the successive sounds of the scale. Give the ratio of vibrations in a sound and its *fifth.* A sound and its *octave.* How are *harmonic* sounds produced?

Fig. 113.



(Fig. 113) is a string stretched and made to vibrate, it may divide into three equal parts, A D, D C, and C B, each part vibrating, while the points D and C remain still. While A D is on one side, D C is on the opposite, and C B the same as A D; and when A D is reversed, the others are also, as shown by the dotted line. The points D and C, which are at rest, are called *nodes*, and they divide the string into the *vibrating segments*, A D, D C, C B. A string, when vibrating in this manner, gives a much higher tone than when vibrating as a whole, as in Fig. 110, because the parts are so much shorter. But these two modes of vibration may exist *together*, and both tones be heard at once. In that case, D and C are not strictly at rest, but only at rest in relation to the parts, into which they divide the whole string. A string may divide in various other ways, and produce sounds of corresponding pitch; but it never divides except into equal parts. The sounds thus produced are called *harmonics*, because, in all the simple divisions, which are the ones most likely to occur, such as halves, thirds, fourths, &c., the sound is in harmony with that of the whole.

207. *Vibrations of a column of air.*—When a musical sound is produced by a tube of any kind, it is the column of enclosed air which is the sounding body. A condensed wave runs back and forth in the tube, followed by a state of rarefaction; and these waves act on the surrounding air, like the ex-

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Show by figure how a string vibrates in parts. Can a string vibrate in parts, and also as a whole at the same time? What are the *nodes?* What are the parts between the nodes called? Why are the sounds thus produced called *harmonics?* State how a column of air vibrates. How are the waves excited?

cursions of a string. The vibrations in a tube are produced, either by a stream blown across an opening in it, as in the *flute*, or by a reed of wood or metal, as in the *clarinet*. Each of these modes is employed in the construction of organ-pipes.

308. The same is true of a column of air as of a string, namely, that according as it is longer, there are fewer vibrations per second, and therefore the pitch is lower. It is obvious, that the number of vibrations is diminished as the length is increased, because the waves have a greater distance to run. Many wind instruments illustrate this fact. All the sounds of the scale are obtained from a flute, by lengthening and shortening the column, which is effected by opening or closing the holes with the fingers or keys. A column of air also, as well as a string, can vibrate in parts, the waves running back and forth through each *half*, or each *third*, &c., instead of through the whole. This is accomplished in the flute, by blowing more swiftly. As the force of the breath is gradually increased, the sound will suddenly change from the former note to its *octave*, the column then vibrating in *halves*; then, by another sudden change, it springs to the *fifth* of the octave, the column then vibrating in *thirds*, and so on. With all holes closed, four or five harmonics are easily produced. The points of division between the vibrating portions are called *nodes*.

309. *Chords and discords.*—It is well known, that some sounds are agreeable when falling *together* upon the ear, and others disagreeable, although in each case the sounds themselves are equally pure and pleasant. Sounds which form a pleasing combination are called *chords*, those which form an unpleasant

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Examples of each? What effect has length on pitch? How is a flute made to give different sounds? How when the same holes remain stopped? Define *chord*. *Discord.*

combination are called *discords.* It is found that the concordance or discordance depends on the *frequency of coincidence* in the vibrations of the two sounds. The most perfect chord is that of a note and its octave. In this case, there is *one* vibration of the lower sound, while there are *two* of the higher; hence the vibrations coincide at every vibration of the lower note. After the octave, the next most perfect chord is that of the *fifth; two* vibrations being made by the lower note, while *three* are made by the higher. Thus the vibrations coincide at every second vibration of the lower note. But if a note and its *second* are sounded together, they grate harshly upon the ear. Here *eight* vibrations are made by one, while *nine* are made by the other, and the coincidences are so distant as to produce a disagreeable roughness.

310. A succession of agreeable combinations constitutes *harmony.* Discords, however, are not entirely rejected from music; a combination which would not please, if prolonged, or used to close a passage, may, if skilfully introduced, greatly relieve the effect, and prevent the sameness of a series of perfect chords.

311. *Interference of sounds.*—Whenever two or more sounds are moving in the air together, the particles have movements which are the resultant effect of the separate motions due to each sound. These motions may conspire or they may oppose each other. The word *interference* is used in general to express the combined effect in any case. The *beats* which sometimes occur, when two sounds reach the ear together, are the

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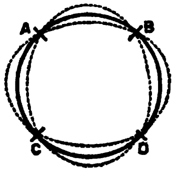
What is the most perfect chord? What vibrations coincide? When the *second* vibration of one sound coincides with the *third* of another, what chord is produced? Give an example of *discord,* and state what vibrations coincide? What is *harmony?* Are discords of use in music? What is meant by interference? How are *beats* produced?

effect of interference in the case where the coincidences of two systems of waves are so far apart as to be heard separately. The beats are at those moments when the condensations and the rarefactions of one sound coincide with those respectively of the other. At points of time half way between the beats, the sound is faintest, because the condensations of one system of waves coincide with the rarefactions of the other, and they partially neutralize each other. It is possible, by a delicate mode of experimenting, to make two systems of waves, which are exactly alike, come together with opposite phases coinciding, and thus destroy all motion, and of course all sound. In this curious case, two sounds produce *silence*, on the same principle that two systems of water-waves may produce level water.

312. *Nodes.*—It has been mentioned, that in the harmonic sounds of strings and columns of air, the vibrating segments are separated by points of rest, called *nodes*. There are many forms of bodies, which produce sound, that can vibrate in no other way except in parts; and in these cases, nodal lines and nodal points, of course, must exist.

Fig. 114.



313. The *bell* is an example. Each circular ring of metal is changed into an ellipse (Fig. 114), and then, as the arcs return and go by their position of rest, another ellipse is formed, with its longest axis at right angles to the former. There are, of course, four points of intersection, A, B, C, D, 90° apart; these are the nodes. As this is true of all the rings which compose the bell, there are four nodal lines, or lines of

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Can two sounds destroy each other? How must phases come together? What are *nodes*, in general? Give an example in the *bell*. Can it vibrate *without* nodes? How does it give different sounds?

rest, extending from the summit to the edge. The lowest tone which the bell can give, is produced in the manner now described. But a bell, especially a large one, as a church bell, usually gives one or two higher tones, which may be faintly heard. These are caused by a greater number of vibrating segments.

314. *Chladni's plates* furnish another very interesting case. They receive their name from Chladni, a German, who first published an account of the experiments. Let a square plate of glass or metal be fastened at its center by a screw (Fig. 115) in a horizontal position; then let a little writing-sand be scattered over it, and a bow drawn on its edge, so as to bring out a musical tone. The sand will dance rapidly over its surface, until it finds the nodal lines, where it will rest. By varying the action of the bow, and moving to different places the point of fixture, nearly a hundred forms of nodal lines have been obtained from the square plate alone; and every new arrangement of the lines corresponds to a new musical tone. Fig. 116 shows four of the forms. Chladni

Fig. 115.

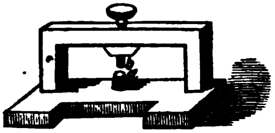
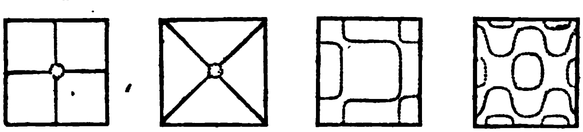


Fig. 116.



Describe the experiments with Chladni's plates. What change accompanies a change of pitch? How many forms of vibrating with the square plate? How does a table increase the sound of a tuning-fork?

tried plates of many different shapes, and found numerous systems of lines peculiar to each.

315. When a tuning-fork is made to vibrate, and the stem of it is touched to a table or other extended surface, the sound becomes much louder. This is caused by the vibrations of the fork being communicated to the table, and thence to the air. But in all such cases, the table divides itself into a system of vibrating segments, separated by nodal lines. If a fork of a different key be applied, the table will divide differently, so as to give the same tone as the fork. And thus the same surface may be made to give forth different tones without number. On the same principle, the *case* of the viol and the guitar is made of thin elastic plates of wood, for the purpose of giving fullness to the sounds of the strings.

Can it do the same for a fork of different pitch? How? The use of the *case* to the violin?

PART V.—ELECTRICITY.

CHAPTER I.

FIRST PRINCIPLES.—THE ELECTRICAL MACHINE.

316. *Indications of electricity.*—Electricity is the name given to a certain fluid existing in all matter, but which becomes apparent only when its equilibrium is disturbed. The first manifestation which electricity makes of itself is in causing *attractions* and *repulsions.* If a glass rod, dry and warm, be rubbed with dry silk, and then presented toward small light bodies, as bits of paper or pith, feathers or straws, they will fly to the rod, and sometimes cling to it, but in other cases are immediately repelled. The silk, to some extent, exhibits the same power to attract and repel. The rod and silk in this case, are said to be *excited.* Other bodies, which receive electricity from them, are said to be *electrified.*

317. *Electroscopes.*—An *electroscope* is an instrument intended to show the presence of electricity, though in very small quantity; an *electrometer* is used for measuring the quantity.

What are the first manifestations of electricity? Describe the elementary experiment. In what state are the rod and silk? If other bodies receive electricity from them, what word describes their condition? Define *electroscope.*

The simplest electroscope is a delicate pendulum (Fig. 117) made of a fine silk thread and a pith-ball, hanging from a support usually made of glass. A more sensitive kind is the *gold-leaf* or *silver-leaf* electroscope (Fig. 118). It consists of a small glass receiver, into the top of which is cemented a brass rod having a ball upon it, and two strips of gold or silver leaf suspended from it within the receiver. An excited or electrified body brought near the ball causes the leaves to separate. For many purposes, it is convenient to use two pith-ball pendulums, hanging side by side from a conductor.

Fig. 117.

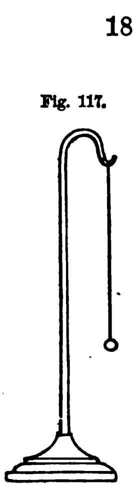
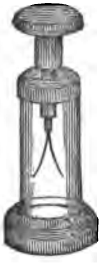


Fig. 118.



318. *Mode of exciting electricity.*—When electricity is by any means made to manifest itself, it is said to be *excited* or *developed.* Although there are several ways of doing this, the usual method of exciting electricity mechanically is by *friction.* Thus, glass rubbed with silk, or sealing-wax rubbed with flannel, instantly developes electricity. A dry sheet of paper, rubbed with india-rubber, adheres to the table, makes a crackling noise when pulled off, and, if applied to the wall of the room, clings to that also. The use of a clothes-brush on warm clothing in cold, dry weather, excites electricity, which is sometimes perceived by the crackling sound which it occasions; and more frequently by the dust flying back upon the garment. Though a few substances, such

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Describe the simplest kind. A more sensitive kind. How is it affected by an electrified body? What is the usual way of exciting electricity? Give examples.

as glass, resinous gums, silk, flannel, &c., are preferred for electrical experiments, yet it is found that electricity is excited by the friction of all substances without exception. It is for this reason that electricity developed by mechanical means is often called *frictional electricity*, in distinction from that modified condition of the fluid, called *galvanic electricity*, which is excited by chemical means.

319. *The two electricities.*—When friction has taken place between two bodies, they are found to be very different from each other in their electrical conditions. Hence, according to the generally received theory, there are supposed to be *two* electric fluids, which ordinarily are mingled and neutralized, but which, by friction, and in other ways, are separated, and thus rendered active. The two fluids are called the *vitreous electricity*, and the *resinous electricity*. In the experiment already described, one is found on the glass, the other on the silk; and so in all cases of friction: the *vitreous* is on one, the *resinous* on the other, of the two bodies rubbed together. If *glass* be rubbed by almost any other substance, it takes the vitreous electricity; and the name *vitreous* is given to it for that reason. But if a rod made of *resin* be rubbed by various substances, it generally takes the other kind of electricity, which is therefore called *resinous*. The theory of two fluids is usually called Du Fay's theory, from the name of its author, *Du Fay*, of France.

320. *Franklin*, of America, proposed a theory of one fluid, which will equally well explain most electrical phenomena. According to Franklin's theory, all bodies, in their natural con-

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What are the two forms of electricity called? Why is the first called frictional electricity? What is the theory generally received? What are the names of the fluids? Why are these names given? Whose theory is it? State Franklin's theory.

dition, possess a certain share of electricity, and show electrical excitation only when they have either *more* or *less* than the natural share. In the first case, they are said to be electrified *positively*, and in the second, *negatively*. A body which has *vitreous* electricity, according to Du Fay's theory, is the same as a body *positively* electrified, according to Franklin's; consequently, a body having the *resinous* electricity, is the same as a body *negatively* electrified. Many writers, who adopt the theory of two fluids, make use of the terms positive electricity and negative electricity, instead of vitreous and resinous electricity.

321. *Mutual action.*—Bodies electrified *in the same way, repel*, and, *in different ways, attract* each other. If the excited glass rod touch the pith-ball of the pendulum electroscope, the ball instantly becomes electrified like it, and flies off, and it is difficult to touch it again, because it is so actively repelled. But if the silk, with which the glass was rubbed, is brought near the pendulum, the ball springs to the silk, being attracted instead of repelled; here the silk is negatively electrified, and the pith-ball positively. Again, if the ball of the pendulum is unelectrified, and a rod of resin, excited by friction on flannel, is brought in contact with it, the ball will as before be repelled by it, both being negatively electrified. But if the glass rod is now brought near, the ball is attracted by that, and it is also attracted by the flannel on which the resin was rubbed; in these cases, the pith-ball is negatively, the glass and the flannel positively electrified.

322. The electrical force, both the attraction and the repulsion, is found to vary inversely as the square of the distance,

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What terms correspond to each other in the two theories? What is the
3 law of attractions and repulsions? Describe experiments to prove it. What
36 is the law of electrical force as to *distance?*

being in this respect like the force of gravity. This law was first proved by Coulomb, by means of an instrument called the *torsion balance.*

323. *Conduction.*—Electricity moves with the greatest readiness on some substances; they are therefore called *conductors.* The metals, water, the bodies of animals, and most mineral substances, are good conductors. But, on the other hand, there are many substances on which electricity does not move at all, or only with great difficulty; these are called *non-conductors,* and sometimes *insulators,* because the fluid can be confined in its place by means of them. The most perfect insulators are gum lac, and other resins, sulphur, glass, silk, hair, wool, feathers, the air. *Copper* is regarded as the most perfect conductor, and gum *lac* as the most perfect insulator; and between these two extremes, there are all degrees of conducting power. Many substances owe their conducting quality chiefly to the water which they contain, as, for example, *wood,* which usually has more or less moisture in its pores. Wood which has been baked till the moisture is driven out, and then varnished, to prevent its imbibing more, is rendered a non-conductor. The air is generally an imperfect insulator, because of the dampness contained in it.

Those parts of electrical apparatus in which the fluid is to be kept from escaping, are insulated by being mounted on glass pillars, and sometimes by being suspended by silk threads.

324. *Electricity at the surface.*—In the natural condition of bodies, every particle is supposed to have its own supply of the

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By what instrument was this proved? What are *conductors?* What are *non*-conductors? What other name for the latter? Name some of the principal substances of each class. What is the best conductor? The best insulator? How is apparatus mounted that it may retain the fluid? When a body is electrified, in what part of it is the fluid?

electric fluids. But when a body is electrified, the single fluid with which it is charged lies at the *surface* of the body, and not at all within the surface. Hence, electrical conductors, when hollow, will contain just as great a charge of electricity as when solid. For the sake of lightness, therefore, the conducting parts of instruments are usually made of sheet brass. For this reason, the capacity of a body for containing a charge of electricity, is measured by the number of square inches of its surface, and not by the number of cubic inches of its material. For example, let a wide metallic ribbon be rolled up into a compact cylinder, and have as full a charge of electricity as possible communicated to it. An electrometer set upon it will show the intensity of the charge. If now, the ribbon be gradually unrolled, so that the same amount of matter has more and more surface, the electrometer falls, showing a less and less intensity of charge; and when the ribbon is again rolled up, the electrometer rises to the mark of highest intensity.

325. *Unequal distribution on the surface.*—There is only one figure on which the electric charge will be spread equally over every part, and that is, the *sphere.* On bodies of every other shape, the intensity will vary, being in general greater as the parts are more prominent, and approach more to a point. Thus, if a conductor has the form of an egg, the electricity will collect most at the smallest end; and then more at the large end than around the middle, where the intensity will be least. And if the extremity is sharply pointed, the electricity will there become so intense as to escape. Hence, in order to retain electricity on an insulated conductor, it must be free from

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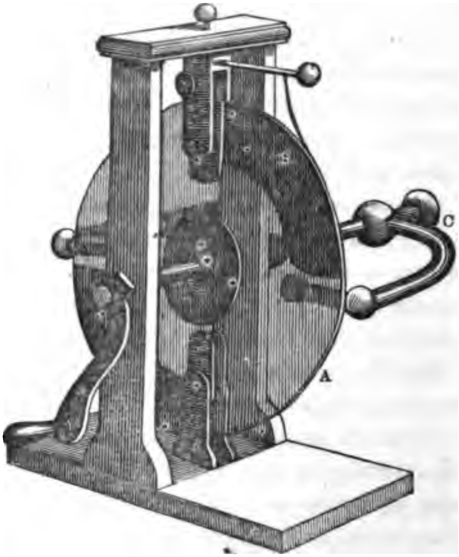
Why are metallic instruments for electricity made hollow? State the effect of enlarging the surface. Describe the experiment. When is the distribution equal? How distributed in other cases? Describe the case of an egg-shaped body.

sharp edges and points. The metallic parts of apparatus are therefore rounded into cylindrical and spherical shapes.

326. *Charge held upon the surface by the air.*—The mutual repellency of electrical particles, which drives them to the surface of a conductor, tends to make them escape from it in all directions; and they would do so, if not prevented by the pressure of the air. If one extremity of an insulated conductor extend into the receiver of an air-pump, and the air be then removed, the electricity cannot be kept on the conductor, and the most abundant supply communicated to it fails entirely to electrify it.

Fig. 119.



327. *The electrical machine.*—The properties of electricity

What forms are given to electrical conductors? Why is the charge at the surface? Why not diffused beyond? How is this proved?

now considered enable us to understand the construction of the electrical machine. This instrument is intended to develop electricity as conveniently and rapidly as possible by the friction of glass. Fig. 119 is one of the forms of the *plate machine*. A is a thick circular *plate* of glass, usually between 1½ and 3 feet in diameter, supported by a metallic axis on two pillars of baked and varnished wood, and furnished with a crank for turning it. There are rubbers of leather at top and bottom, pressing against both surfaces of the glass. At C is the *prime conductor*, made of hollow brass, and insulated by glass supports, not represented in the figure. There are sharp points on the prime conductor near the glass, for transmitting the fluid; but all other parts are rounded, to prevent waste. Silk covers also protect the glass between the rubbers and the points of the conductors, that the electricity may not escape into the air. The vitreous electricity excited on the glass causes a vitreous charge on the prime conductor, where it is retained for use.

328. In the *cylinder machine* the glass is a hollow cylinder, whose length is greater than its diameter, and the rubber is applied to the convex surface on one side, while the points of the prime conductor are presented to the opposite side. Small machines are often of this construction.

329. When the glass of the electrical machine is turned, the friction between it and the rubbers causes a separation of the fluids. The vitreous lies on the glass, while the resinous follows the conducting pillar of the rubbers to the earth. Sometimes the rubbers are insulated by a glass pillar; and in that case, a chain must be suspended from the rubbers to reach the

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Describe one form of electrical machine. What are the names of the two kinds? Which kind used for small machines? Describe the operation of the machine. Where is the developed electricity kept? Why are points attached to the prime conductor?

floor, in order to conduct off the resinous electricity. The vitreous electricity of the plate attracts the resinous from the prime conductor, so that the latter is left charged with vitreous. The points on the prime conductor facilitate the passage of the fluid to the glass (Art. 325).

330. An electrometer set upon the prime conductor shows the intensity of the charge. The electricity is more rapidly developed if the rubbers are coated with some metallic preparation, as an *amalgam* of zinc, tin, and mercury, or a compound of sulphur and tin, called the *bi-sulphuret of tin*. When an electrical machine is in good working condition, the prime conductor will be as fully charged as possible in one or two revolutions, and the electricity will then escape with slight crackling and hissing sounds into the air, and in a dark room the escaping fluid is visible in the form of delicate brushes of light.

CHAPTER II.

ELECTRICAL INDUCTION.—THE LEYDEN JAR.

331. *Electrified by induction.*—When a conductor is insulated, and placed near an electrified body, yet not in communication with it, it nevertheless becomes electrified by the separation of its own electricities, and is said to be *electrified by induction*. Thus, let the body A (Fig. 120) be positively

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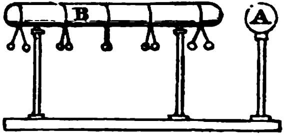
How is the intensity of the charge indicated? How soon is the prime conductor charged as full as possible? What becomes of the excess? What effect is produced when an electrified body is placed near one not electrified? How is the effect shown? What is this effect called?

Fig. 190.



electrified, and let the conductor B, resting on insulating supports, be brought near, but not so near as to receive any electricity from A. It will be found that the nearest end of B is negatively electrified. If electroscopes are attached to different parts of B, those at the extremities will diverge most, and the others less and less toward the middle, where there is no sign of electricity. If the electricity is taken away from A, then B loses all indications of electricity, although it remains insulated. Again, let A be negatively electrified, then the nearer end of B will become positive, and the remote end negative. In general, the end nearest to A is always charged *unlike* A, and the remote end is *like* A.

332. Induction is explained thus. If A is positively electrified, then the vitreous fluid on A attracts the opposite, that is, the resinous fluid of B to the nearer end, and repels the like kind (the vitreous) to the remote end. If A is removed, or if it loses its charge, then the two fluids in B mingle together again, in consequence of their mutual attraction, and B returns to its natural condition. On the contrary, suppose A to be charged with the resinous fluid; then it attracts the vitreous of B to the nearest, and repels the resinous to the furthest extremity. Thus, in each case, the latent electricities of B are separated from each other by the attracting and repelling force of the electricity contained in A.

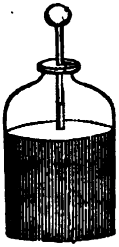
333. The principle of induction explains why an electrified

What is the condition of the nearer part? Of the remote part? Explain why. Does the body remain in this condition after the electrified body is removed? Why?

body always *attracts* a light body not electrified. The light body is *first* electrified by induction, the nearest part *unlike*, and the further part *like*, the electrified body which is brought near it. The near part is therefore attracted, and the further part repelled; and according to the law of distance (Art. 322), the attraction is greater than the repulsion, and the body yields to the greater force.

334. *The Leyden jar.*—This instrument, so named from the city where it was invented, is a bottle (Fig. 121) covered both on the inner and outer surface with tin-foil, to within about three inches of the top. Through the cover passes a wire which touches the inner coating, and has a ball on its summit. It is used for accumulating large quantities of electricity by means of induction. In the experiment described (Art. 331), only small surfaces of A and B are brought near each other, and these not nearer than three or four inches, lest the fluid should pass across from one to the other. Suppose the adjacent surfaces of the two bodies to be expanded into many square inches or feet, and brought close to each other, while a plate of glass is interposed between them, so that the electricity cannot pass across; then the attractions and repulsions become vastly increased, and may be employed for condensing the fluids in large quantities. The Leyden jar has such a construction; the two coatings are extended metallic surfaces, very near each other, and yet the glass between them prevents the electricity from passing from one to the other.

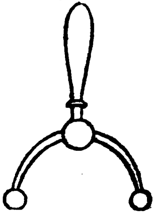
Fig. 121.



Why does an electrified body always attract one not electrified? Describe the Leyden jar. What is its use? Why is the inductive influence greater than in the case described? Why may the conductors be brought so near each other?

335. The jar is charged by bringing the knob near to the prime conductor of the machine while in operation, the outer coating being held in the hand, or in some other way being in communication with the earth. A series of sparks, more or less in number, according to the size of the jar, will pass from the prime conductor to the knob, until at length they will cease, when the jar is fully charged. To discharge it, use the *discharging-rod* (Fig. 122), which consists of bent rods terminated with balls, and hinged together upon an insulating handle. On applying one ball to the outer coating, and the other to the knob of the jar, the discharge takes place with great suddenness, accompanied with a brilliant flash and a sharp report. The jar may be discharged, however, by connecting the inner and outer coatings by any conductor whatever. The two electricities, which are condensed, one in one coating, and the other in the other, rush violently together, as soon as a conducting circuit gives opportunity.

Fig. 122.



If one hand is touched to the outer coating, and the other to the knob, then the discharge is made through the body, and causes the sensation called the *electric shock*.

336. When the knob is held to the prime conductor, and the outer coating is connected with the earth, as already described, the jar is said to be charged *positively*; but if the outside were brought to the prime conductor, and the knob held in the hand, it is *negatively* charged; the charge in each case being named from the condition of the *inner* coating.

How is the jar charged? How is it discharged? Describe the discharging-rod. Can the discharge be made without it? How is the *shock* received? When is the jar *positively* charged? When *negatively*?

337. *Charging of the jar explained.*—The process of charging a jar is explained as follows. The first sparks of the vitreous fluid which pass into the inner coating, repel the same kind from the outer coating to the earth, and attract the resinous of the outer coating more closely to the glass. The resinous fluid now on the outside attracts the vitreous of the inner coating more closely to the glass, giving room for more sparks to pass from the prime conductor to the inner coating. This additional quantity within expels more vitreous from the outer coating to the earth, and attracts more resinous from the earth to the outside; and so on in a diminishing series, till the jar is charged.

338. Without this mutual inductive influence between the two coatings of the jar, there would be no more accumulation on its surface than on the prime conductor. This is proved by setting the jar on an insulating stand, and then presenting the knob to the prime conductor. Two or three sparks pass to the inner coating, and then the process stops; for, in this case, the vitreous fluid on the outside remains to repel the vitreous of the machine, and prevent any further accumulation.

339. *Phenomena of the jar.*—The jar may become so intensely charged that it will discharge *spontaneously*, the spark passing over the edge of the glass, with a flash and report. If the glass is damp or much soiled, the spontaneous discharge will take place silently, or with only a hissing noise, nearly as fast as it is charged.

340. If several jars are insulated, and the outside of the first is connected with the knob of the second, the outside of the second with the knob of the third, and so on, the outside

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Explain the process of charging the jar. Why can more electricity be obtained than on the prime conductor? How must the two coatings be connected? State the effect when the jar is on an insulating stand. How is the jar discharged spontaneously? Describe the charging of a series of jars.

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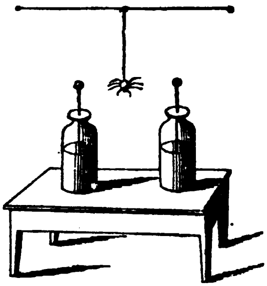
of the last one alone being connected with the earth, then the whole series will be charged as soon as the first is, and without requiring any more electricity from the machine. This is because the vitreous fluid driven from the outside of the first jar goes to charge the inside of the second, and so of the others. Hence the charging of the first causes each one of the series to be charged, though the intensity is less from jar to jar through the whole.

341. If two jars be charged in opposite ways, and set upon a table, and a pith-ball be suspended by a long thread between the knobs, it will vibrate from one to the other for a long time (Fig. 123). It will first move to the knob which happens to attract it most strongly, when it becomes electrified like it, and is repelled and attracted by the opposite electricity in the other. It then loses its former charge, and becomes electrified like the knob which it touches, so as to be repelled again. The *electrical spider*, the *see-saw*, the *ringing bells*, &c., are experiments of the same character.

Fig. 123.



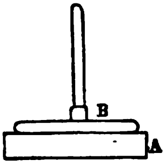
342. If a jar with movable coatings is charged, the coatings may be taken away without removing the charge; and if other coatings are applied, the jar may then be discharged as well as by the first pair. This is because the attraction between the two fluids holds them closely upon the glass, while the coatings are exchanged.

Why is no more fluid from the machine needed than to charge one? Describe vibration experiments with two jars. If the coatings of a charged jar are removed, is the electricity removed? Why?

343. A jar will retain its charge in pure dry air for days and even weeks, because the attraction between the two kinds of electricity on opposite sides of the glass, prevents their dissipating in the air. But electricity, when not thus held by the inductive force, will soon escape; as, for instance, the charge of the prime conductor will remain only a few minutes, since by its own repellency it tends to fly off in all directions, and there is no attractive force to prevent.

344. *The electrical battery.*—Jars are of various sizes; but rather than to make one very large, it is more convenient to unite several in a box, called a battery. The outside coatings are all connected by lining the box with tin-foil, and the inner coatings by wires joining to one stem or ball. Four, nine, or twelve jars are thus often united in a battery.

Fig. 124.



345. *The electrophorus.* — This instrument is sometimes used as a small electrical machine. It consists of a flat cake of resin in a wooden base A (Fig. 124), and a metallic disk B, having an insulating handle. The resin is first rubbed with fur, and becomes excited with the resinous electricity; the disk is then set upon it, and touched with the finger. If the disk is now raised by the handle, and the knuckle, or any conductor brought near, a brilliant spark leaps to it from the disk. Place it again on the resin, touch it, and then take it up as before, and another spark is drawn from it; and this may be repeated hundreds and even thousands of times; and after the instrument has stood for hours, it is still ready to oper-

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Why will a jar remain charged a long time? Describe the *battery*. Explain the construction and operation of the *electrophorus*. Is the charge of the resin wasted by inducing the charge upon the disk?

ate equally well without being again excited. The principle of induction explains its action. When the disk is placed on the resin, and the finger touched upon it, the resinous fluid attracts the vitreous from the earth into the disk, and holds it there until the disk is raised, when the vitreous charge can be taken off. On setting down the disk and touching it a second time, the same process is repeated; and thus a single charge on the resin may draw from the earth as many vitreous charges as we please, without being wasted at all itself.

346. *The gold-leaf electroscope.*—This article was described in Art. 317; but its action can be explained only on the principle of induction. Let a glass rod be excited by rubbing it with silk, and held near the knob of the electroscope; then the vitreous electricity of the rod repels the vitreous of the knob into the leaves below, and at the same time attracts the resinous from the leaves up to the knob; thus the leaves are both charged with the same fluid, and repel each other. The same effect would be produced by bringing near to the instrument a body charged with the resinous electricity; the leaves in that case would be electrified with the resinous fluid, and so, being alike, repel each other as before.

Use the principle of induction to explain the action of the gold-leaf electroscope.

CHAPTER III.

EFFECTS OF ELECTRICAL DISCHARGES.

347. *Luminous effects.*—Electricity occasions light whenever it passes in sufficient quantities through non-conductors. Thus, if a wire terminating in a ball be presented to the prime conductor, when the machine is in operation, a spark of white light darts across the interval occupied by the air; but if the wire is brought into contact with the prime conductor, no light appears. It is the obstructing air which occasions the light; if the air is more dense, the light is brighter; but if it is rarefied, the light becomes gradually fainter, and ceases altogether when the fluid passes through a vacuum.

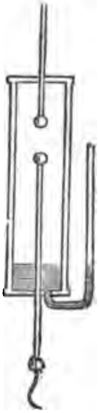
348. *Modifications of the light.*—The brightness and color of the light are varied in many ways. The short sparks from the prime conductor to a ball are straight and white; the longest which can be taken are crooked, and of a purplish tint. If a pointed wire is attached to the prime conductor, the electricity flows off in a delicate brush of light, too faint to be seen except in the dark. As air is rarefied by the air-pump, the color gradually changes from white to violet, and grows faint and more diffused. A spark sent through the vapor of ether is green; through the vapor of alcohol, it is red or blue. The discharge of a jar through different solid non-conductors appears also of various colors; as, for instance, through an egg it is crimson; through the pith of corn-stalk it is orange, &c.

When does electricity occasion *light?* Effect of changing the density of the air? Of making a perfect vacuum? Mention circumstances which modify the light. What is the color of the light in rarefied air? Through an egg? Pith of corn-stalk?

349. *Luminous figures.*—Since the electricity is visible whenever there is the slightest interruption of the conductor, luminous words, and figures of any kind, may be exhibited by cementing narrow strips of tin-foil on glass, and then cutting minute interruptions in them according to the required arrangement. The *spiral tube* has a line of tin-foil fastened spirally around the interior of the glass, interrupted at numerous points, so that, as the fluid passes, it appears like a brilliant coil of light. The *diamond jar* is one whose coatings are interrupted in such a manner that the electricity becomes visible all over it, while receiving a charge, and far more brilliantly when discharged.

350. *Mechanical effects.* — Powerful electric discharges through imperfect conductors produce certain mechanical effects, such as perforating, tearing, or breaking to pieces. These effects are due to the violent repulsion between the electrified particles. The *air* is rent by a discharge, the particles being suddenly repelled from each other along the line; and it is for this reason that there is so sharp a report attending the discharge of a jar. Kinnersley's instrument (Fig. 125) shows the effect of this sudden rupture of the air. The rods at the top and bottom of the instrument being connected with the coatings of a Leyden jar, a discharge is made, and the spark leaps across the space between the knobs in the enclosed air, and causes a sudden pressure on the water, driving it up the small tube. If a charge is sent through pasteboard, or several thicknesses of pa-

Fig. 125.



How are luminous figures produced? Describe the *spiral tube*. The diamond jar. What *mechanical* effects are produced by large discharges? Why? What causes the sharp sound? Describe Kinnersley's instrument, and explain.

per, a perforation is made with edges protruded on each side. A minute puncture may also be made through glass; but if the charge is too powerful, the glass is likely to be cracked to pieces. Pieces of hard wood, of loaf sugar, and other brittle non-conductors, are rent in pieces by the charge of a battery.

351. When a charge is sent through a conductor, it ordinarily produces no effect, because it is diffused over the whole dimensions of the body in passing, and the repellency is therefore small; but if the conductor is reduced to a slender line, as, for example, a thread of mercury in a thermometer tube, then the force is limited to so few particles, that they are violently driven asunder, and the tube is shattered to pieces.

352. *Chemical effects.*—These are various; combustion of inflammable bodies; the oxydation, fusion, and combustion of metals; the separation of compounds into their elements; and the reunion of elements into compounds.

353. Ether and alcohol are readily inflamed by the spark of the machine; phosphorus, resin, turpentine, &c., may be set on fire by the discharge of a jar; gold leaf and fine steel wire are burned by that of a battery. Indeed, any of the metals in an attenuated form may be burned; that is, they combine with the oxygen of the air, and form oxides.

354. *Velocity of electricity.*—This is so great that no appreciable time is occupied in any case of discharge. We imagine that we see lightning go from the clouds to the earth; but in fact, the whole line is seen at once, and, by a little effort, we can seem to perceive it *ascending* as well as descending. It has been discovered by Wheatstone that frictional electricity on

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Are conductors affected like non-conductors? Give the reason. Effect of a discharge, through the mercury of a thermometer? State the chemical effects. What velocity did Wheatstone find electricity has on copper wire?

copper wire, one-fifteenth of an inch in diameter, travels at the rate of 288,000 miles in a second, a velocity much greater than that of light.

The galvanic electricity used for telegraphic purposes, moves at the rate of about 16,000 miles per second.

CHAPTER IV.

ATMOSPHERIC ELECTRICITY.—NATURE OF ELECTRICITY.

355. *Electrified condition of the air.* By elevating a tall metallic rod, and insulating it, or by sending up a kite and insulating the string, it has been discovered that the air is generally electrified. Sometimes it is in the positive, sometimes in the negative condition. In fair and settled weather the air is usually positive; in stormy weather it varies from the positive to the negative, and the reverse. But clouds are more likely to be highly electrified than pure air; and when they are so strongly charged that the spark leaps off to another cloud, or to the earth, we witness a *flash of lightning.* Dr. Franklin was the first to observe the many points of resemblance between lightning and the discharge of the Leyden jar. In 1749, he published an account of these, and proposed that experimenters should endeavor to obtain electricity from the clouds, by erecting tall iron rods. This was first done by Dalibard in France; and in 1752, he himself performed the usual experiments by

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Can we *see* whether lightning descends or ascends? What is the velocity of *galvanic* electricity, in conveying telegrams? How is the electrical condition of the air ascertained? In which way is it usually charged? Who first noticed the resemblance between lightning and the spark of a jar?

means of electricity brought down on a kite-string during a thunder-shower. That lightning is identical with electricity is acknowledged by all to have been a discovery of Franklin.

356. *Thunder-storms.*—Clouds are not all electrified in an equal degree. Those of slow formation, especially if they are of great extent, are feebly charged; while such as are more limited, and are formed in the midst of violent agitation of the air, are most likely to be highly electrified. A storm of this character is called a *thunder-storm*, because of its discharges of lightning and thunder. In general, such storms occur in the hottest season of the year, and the warmest part of the day, and they prevail most in those localities in which warm moist air is borne from the ocean over an uneven, especially a mountainous country. The storm is not supposed to be *caused* by electricity, but to be produced in the same manner as other storms, while the electrical phenomena are due to some peculiar circumstances attending their formation.

357. *Lightning and thunder.*—If a cloud, as it is forming, becomes electrified with rapidity, its accumulated electricity acts by induction on other clouds, and on the earth, causing their nearer parts to be electrified in the opposite manner, in consequence of which attraction exists between them, so that the two fluids tend to rush together; and when this takes place, the bright electric spark is seen as *lightning*, and the violent rending and collapse of the air is soon after heard as *thunder*. The line of discharge has the same crinkled form as the longest sparks from the prime conductor. This is supposed to arise both from the condensation of air, which impedes the motion,

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Did he first prove their identity? Was he then the discoverer of it? When are clouds most likely to be charged with electricity? Does electricity *cause* the storm? What effect does an electrified cloud produce on other bodies? What is lightning? What is thunder? Why is lightning crooked?

and turns the fluid aside continually into new directions; and also from the arrangement of conducting particles which may be floating in the air. The inequalities in the sound of thunder are in part due to the *crookedness* of the line, which causes different parts of the path to be at various distances from the ear, and the sound comes sooner as the distance is less, while from all equidistant portions, the sound comes at the same time with increased loudness. But the *echoes*, produced by clouds, hills, &c., are likewise concerned in occasioning both the prolongation and the reverberations of thunder.

358. As the two electricities, one in the cloud and the other in the earth, attract each other, and at length leap forth and mingle together in the intervening space, there is just as truly a motion from the earth as from the cloud; hence, if injury is done, it is by the *ascending* rather than by the *descending* current. The injury is caused by the great quantity of fluid, and the inconceivably short time in which it passes. It is proved by experiment that the discharge of a large battery will not harm a person, if it can be made to occupy as much as a second or two of time in passing through him.

359. The words *chain-lightning*, *sheet-lightning*, and *heat-lightning*, are not supposed to indicate any real differences in the lightning itself, but only in the situation of the observer. If he sees the line of discharge, it is *chain*-lightning; if only the light which proceeds from it, *sheet*-lightning; and if, in the evening, the shower is so far off that the thunder is not heard, but only the light of its discharges is discerned along the horizon, this is called *heat*-lightning.

Why is the sound of thunder so irregular? Which way does the fluid move in fact? Why does it injure persons? How may the discharge of a battery be made harmless? Explain the difference between different sorts of lightning.

360. *Lightning-rods.*—Franklin first proposed to defend buildings and persons from the injurious effects of lightning by the use of iron conductors, imbedded in the earth at the lower end, and at the top being pointed, and projecting as high as convenient into the air. These rods, being better conductors than the animal system, and the principal materials of houses, would therefore be most likely to become the channels of communication for electricity between the earth and clouds. The points at top cause the fluid, which is attracted up into the rods, to flow off easily to mingle with the opposite electricity above. Thus, the union of the two fluids is effected continually and silently, as long as the electrified cloud remains near. The purpose of the lightning-rod is not, therefore, so much to give direction to discharges of lightning, when they occur, as to *prevent* lightning to some extent, by carrying on a silent commingling of the two electricities. And a large number of rods in a village does almost entirely prevent lightning from striking within its limits.

361. All extended metallic masses about a building, such as tin roofs, water conductors, bundles of bell-wires, &c., should be connected with the lightning-rod and with the earth, so as to allow the fluid to divide and follow these conductors, without doing damage at interruptions.

362. *Protection of the person.*—The best situation for safety in a thunder shower, is to be near a good conductor, which extends into the earth, and to a considerable height in the air; in other words, to be in the vicinity of one or more good lightning-rods. If a building is not furnished with a rod,

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Why do lightning-rods protect? What particulars should be attended to in putting them up? State the effect of many rods in a town. What should be done with regard to tin roofs, &c.? Explain the reason. How is the person best defended?

it is safer to be in the middle of a room than near the walls; and to sit rather than stand; because, in this way, a person is less likely to form a part of a line of conductors through the building. To dress in silk, or to lie on a feather-bed, or simply to be in contact with a non-conductor of any kind, affords no protection whatever, because the lightning will follow a line of conductors just as freely among non-conductors as elsewhere. Non-conductors are no defense except when they envelope the person to a considerable extent on every side.

363. *Nature of electricity.*—It is customary to describe the phenomena of electricity as though they were caused by the movements of one or more *fluid substances.* This supposition, however, is not made because philosophers *know* that electricity is material, like water or air, but only to give definiteness to the statements which are made. There is no proof that electricity possesses any of the common properties of matter, such as impenetrability, inertia, or gravity. Sometimes *light*, *heat*, *electricity*, and *magnetism*, are called *imponderable* substances, that is, substances *without weight.* But it is quite probable that all of them consist of *vibrations* in some ether or subtle fluid that fills space. *Sound* is not a substance, but consists of vibrations in air or some other medium. And it is at the present day considered almost certain that *light* is not a substance, but only a system of undulations in a delicate ether which exists everywhere. In like manner, perhaps evidence will at length be obtained, that electricity and magnetism are not *fluids*, but only rapid *motions* in some invisible fluid or ether. But until such evidence is found, a clearer knowledge of the facts will be con-

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How, when in a house without rods? Do non-conductors defend? Why? Is it known that electricity is a *substance?* Why discussed as if it were? What are the *imponderable* substances? What is probably their nature? Is *sound* a substance? What is it?

veyed to the pupil, by considering electricity and magnetism as fluids which possess the power of attracting and repelling, of moving from place to place, and of adjusting themselves in a state of equilibrium according to certain laws.

PART VI.—MAGNETISM.

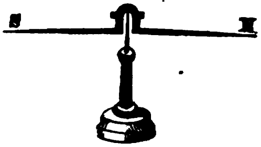
CHAPTER I.

GENERAL PROPERTIES OF MAGNETS.

364. *Definitions and remarks.*—A *magnet* is a body, either natural or artificial, which possesses the property of attracting iron, and of placing itself, when free to move, in a certain position in relation to the earth. The *natural* magnet, called the *lodestone*, is an oxide of iron sometimes found among ores, having the properties just named. The *artificial* magnet is a bar of tempered steel of regular form, in which the same properties have been developed. The artificial magnet is usually employed for experiments, because much more convenient than the lodestone.

365. There are two points at opposite extremities of the magnet, where the magnetic force is stronger than elsewhere; these are called its *poles;* and the straight line which joins them is called the *axis*. If the magnet is delicately suspended at a point midway between the poles (Fig. 126), it will generally begin to turn round, and after a few oscillations will at most places settle itself with the axis nearly in a north and south line.

Fig. 126.



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1 Define a *magnet*. 2 What two kinds? Which is employed for experiments? 3 Define the *poles* and the *axis*.

The end which is directed toward the north is called the *north pole;* the other, pointing southward, the *south pole.* An artificial magnet has its north pole marked in some way to distinguish it from the south pole; sometimes the ends are stamped with the letters N and S, respectively.

366. *Action of the magnet on iron.*—When the pole of a magnet is presented to a piece of iron which is free to move, the iron is drawn toward it; or, if the magnet is free, it is drawn toward the iron; and if brought in contact, they will cling together with considerable force. Both poles act alike in attracting iron, and in being attracted by it. Hence, when a magnet is laid among iron filings, they will attach themselves about the extremities, but in less and less quantities toward the center; the middle of the magnet, where none adhere, is called the *neutral* point.

367. The metals *nickel* and *cobalt* are also affected by the magnet in the same manner as iron is; but as these substances are rare, they are not used in experiments on magnetism.

368. *Action of magnets on each other.*—When magnets are brought near to each other, poles of the *same* kind *repel,* and poles of *opposite* kinds *attract.* Thus the north pole of one repels the north pole of the other, and attracts its south pole; and the south pole of the first repels the south pole of the second, and attracts its north pole. In Fig. 127 (left hand), the N pole of a magnet is held between the *n* poles of two needles, and repels them; (right hand), the S pole is held between, and attracts them. This law is analogous to that in electricity, where like kinds repel, and opposite kinds attract each

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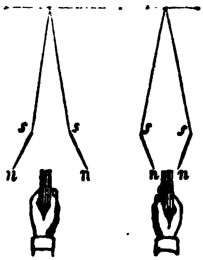
How does the magnet place itself when free? What are the extremities called? How marked? What takes place when iron is presented to a magnet free to move? A magnet among iron filings? Does a magnet affect any other substances in the same way? State how a magnet acts on another magnet. Explain Fig. 127.

other. And one theory of magnetism resembles Du Fay's theory of electricity, in supposing two magnetic fluids, which naturally reside in iron in a combined state, but which may be separately developed, one in one end of the magnet, and the other in the opposite end. These two fluids are called respectively the *boreal* and the *austral* magnetism. The earth being regarded as a great magnet, the boreal magnetism is supposed to be developed in its *northern* hemisphere, and the austral in the *southern*, as the words imply. Therefore, a magnet, when suspended, will turn the end charged with austral magnetism towards the north, and that having the boreal, towards the south, because opposite kinds attract each other.

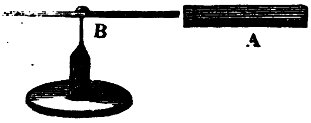
Fig. 127.



369. The law of magnetic force is the same as that of electrical force, *it varies inversely as the square of the distance.* For example, if the unlike poles of two magnets are brought *five* times nearer together, they attract each other *twenty-five* times more powerfully.

370. *Magnetic induction.*—As an electrified body electrifies by induction another one situated near it, so a magnet induces the magnetic state on a bar of iron brought near to one of its poles. That end of the iron which

Fig. 128.



Compare with electricity. State the theory. What are the names of the two fluids? How situated in the magnet? How in the earth? State the 7 law of magnetic force as to distance. Explain the meaning of magnetic induction.

is nearest to a pole of the magnet, will be magnetized by the opposite kind, and the remote end with the same kind. Thus (Fig. 128), if the left-hand extremity of the magnet A is its north end, the right-hand end of the iron needle B is south, and its left-hand end is north; and B is now a *magnet*, being rendered such by induction. It is not necessary, however, to place the two in one straight line, but they may be inclined at any angle with each other, or even be placed parallel, side by side. Indeed, this is the position for the most powerful induction, because each pole now operates to induce the opposite kind of magnetism nearest to itself, and the like kind on the distant end; so that the iron becomes at least twice as strong a magnet as by the action of one pole alone.

371. *Double induction.*—If the *north* pole of a magnet is applied to the *middle* of an iron bar, then two separate inductions occur; each half of the bar becomes a magnet, with the *south* poles in the middle, and the *north* poles at the ends. If the *south* pole be applied, then the halves of the iron bar will have their north poles at the center. If one pole be applied to the center of a star-shaped piece of iron, or of a simple iron circle, the extremity of each radius will have the same kind of magnetism as the applied pole, while the center has the opposite kind. Again, if the *unlike* poles of the two magnets touch the extremities of the iron bar, those ends will be unlike each other, forming twice as powerful a magnet as by the induction of one pole alone. But, if *like* poles be applied at the ends, two magnets are formed, just as when a pole is applied to the center. If unlike poles are applied to the same end of a bar of

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Illustrate by Fig. 128. What position is best? State cases of double induction. Pole on middle of a bar. Unlike poles at the ends. Like poles at the ends. Unlike poles at the same end.

iron, there are two contrary inductions, which neutralize each other, and the iron bar does not become a magnet.

372. *Reflex influence.*—Since the iron bar, when near a magnet, becomes a magnet itself, it ought to act inductively on the original magnet, and increase its power. This actually occurs; and a magnet is in fact strengthened by keeping a piece of iron attached to its poles, which thus exerts a reflex influence upon it. This proves that magnetism is not *imparted to* iron, but only *developed in* it.

373. *Coercive force.*—*Soft iron* readily acquires the magnetic state, and as readily loses it; but *hardened steel* acquires it with difficulty, and retains it permanently. That quality in hardened iron and steel, which hinders the development of magnetism, and which also prevents its readily returning to a neutral state, is called the *coercive force.* To render this force as small as possible, the iron is made pure and soft; but, in order that magnets may be preserved for a long time, they are made of steel and exceedingly hard. The coercive force in a bar may be weakened for the time being, by causing it to ring by striking it with a hammer, and it may be destroyed by heating it to redness. Hence a steel bar may be magnetized by placing it when red-hot between powerful magnets and suddenly cooling it. The coercive force is thus destroyed while the development takes place, and is then restored so as to render its magnetism permanent. If a magnet, however, is heated, when *not* under inductive influence, it loses the force which before preserved its magnetisms in a separate state, and it ceases to be a magnet; in like manner, if a magnet is made to ring, or is

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Does the iron react on the magnet? In what way? Why should it? State the difference between soft iron and hardened steel. What is the coercive force? How is it increased? How weakened? How used for making a magnet? What is the effect of careless handling of magnets?

handled roughly in any way, its powers are impaired, not because any magnetism leaves it, but because the fluids are free to mingle and neutralize each other.

374. *Magnetism not communicated.*—When a magnet is applied to iron, and the latter becomes itself a magnet, it is not because any portion of the magnetism passes from the magnet into the iron; for the magnet loses none of its strength, but, on the other hand, it gains a little, as stated Art. 372. But the iron becomes a magnet, because the magnetisms, naturally latent in it, are developed by the influence of the magnet brought near. Not only does magnetism never pass from one body into another, but the two fluids are not even *separated* from each other in the same bar; for it is readily proved, that there is just the same amount of each kind of magnetism at the neutral point, as there is of either kind at the extremity. Let a magnet be cut or broken in the middle, and immediately the two poles show themselves at the point of division, one in one piece, and the other in the other; then each half may be divided in the same manner, and with the same result. Therefore a magnet *develops* or *brings into action* the magnetisms of the iron, but does not cause them to *separate* and move to different ends. This is one particular in which magnetism differs from electricity; since the latter, when induction takes place, *moves* by attraction or repulsion to the end of the rod; and the fluid also passes from one body to another.

375. *Equilibrium of a needle near a magnet.*—If a magnetic needle, free to revolve, is brought near to a magnet (Fig. 129), it will assume a certain direction, according to the place

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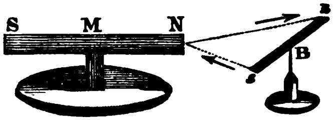
Is magnetism imparted? Does it pass from one part of a body to another? How is this proved? Describe the experiment of dividing a magnet. Is magnetism like electricity in this respect? State how a free needle places itself at the end of a magnet.

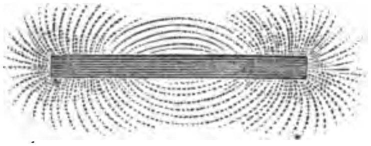
Fig. 129.



of its center. Thus, if the center B is in the line of the axis of the magnet S N, the needle will oscillate until it settles in the same straight line, with opposite poles contiguous. This is because N attracts *s* to the nearest point, and repels *n* to the greatest distance. The pole S tends to repel *s* and to attract *n*; but, being farther off than N, its power is less. If the needle is placed by the side of M, so that B is half way from S to N, then it will turn round until it is parallel to the magnet, with *s* toward N, and *n* toward S; for in that position the pairs of opposite poles, being equally near to each other, will attract with equal power.

376. If the center of the needle is placed elsewhere, the needle will assume positions more or less oblique to the magnet, and may be made to incline to it at every possible angle. All these positions of the needle are exhibited at once by iron filings spread on paper, while a magnet lies below. Every particle of the filings becomes a magnet by induction, and places itself as a small needle would do, with its center at the same place. Thus (Fig. 130) the filings at the ends are in the line of the axis; those on the side, midway from pole to pole, are parallel to the bar; while others between these

Fig. 130.



On the middle of the side. At intermediate points. Why does it take these positions? Explain each case. How are all these positions shown at once?

incline at various angles, forming curves called *magnetic curves*. When a magnet is dipped in filings, the filaments which attach themselves diverge in all directions from each other, and tend, so far as their weight allows, to assume the positions of these curves.

CHAPTER II.

RELATIONS OF THE MAGNET TO THE EARTH.

377. *Declination of the needle.*—When the needle is balanced horizontally and free to revolve, it does not generally point exactly north and south; and the angle by which it deviates from the meridian is called the *declination*, or sometimes the *variation* of the needle. The vertical circle passing through the needle at a given place, is the *magnetic meridian* of that place. The declination at different places is generally different; but lines can be traced passing through a series of points in which the declinations are *equal;* such lines, on the western continent, lie in a northwest and southeast direction, but in many parts of the earth are very irregular. These lines are called lines of *equal declination;* and the line of *no declination* is selected as the standard line of the system. It passes through Hudson's Bay, Lake Erie, and the States of Pennsylvania and North Carolina. It touches the northeast part of South America, and, in the eastern continent, crosses Australia and the Caspian Sea. On the American continent, those places which lie *east* of this line have a *western* declination; that is, the north

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What are the *magnetic curves?* 3 What is magnetic *declination?* 4 State what is meant by the line of no declination. Describe its course.

end of the needle points west of north; and in places *west* of this line, there is *eastern* declination. But on the eastern continent this is reversed; places *east* of the line of no declination have *eastern* declination, and those *west* of it, *western* declination. As a line is imagined to pass through all points of *no* declination, so lines may be supposed drawn through all places having any given declination, as 5° east, 5° west, 10° east, &c., until the whole earth is covered by this system of lines. A chart thus prepared is called a *declination chart*, and is of great service to the navigator.

378. The declination of the needle at a particular locality does not remain permanently the same, but slowly changes, and in the course of centuries may become widely different. In other words, the system of lines of equal declination is gradually moving either east or west, and then returning. It requires several centuries to make a complete oscillation.

379. Besides this great and slow oscillation, there is a minute one each day called the *diurnal* variation. In the early part of the day the needle declines a little to the east of its mean position, and in the latter part of the day to the west, passing over an arc of eight or ten minutes. This motion is greater in summer than in winter.

380. *Dip of the needle.*—A needle first balanced on a horizontal axis, then magnetized and placed in the magnetic meridian, will assume a fixed relation to the horizon, the north pole usually being depressed in northern latitudes, and the south pole

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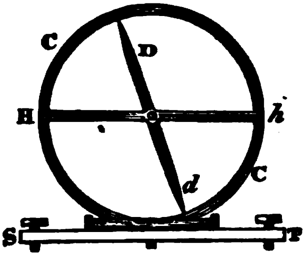
Which way is the declination on the east of this line, in the western continent? On the west side of it? Is it so in the eastern continent? What system of lines is drawn on a declination chart? Is the declination always the same at the same place? What is the movement? Describe the *diurnal* variation. How is a *dipping*-needle balanced? What position does it take generally in the northern hemisphere?

Fig. 131.



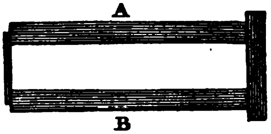
in southern latitudes. This depression is called the *dip* of the needle. Fig. 131 represents the *dipping needle*, with its adjusting screws and spirit-level, and the dip may be read on the graduated circle. In the New England States, the dip of the north pole is as great as the figure represents, about 75°. Near the equator there are points where the needle has no dip. A line passing through all such points is called the *magnetic equator of the earth.* It is somewhat irregular, but passes around the earth, nowhere departing more than 12° from the geographical equator. At every place north of this line, the north pole of the needle dips; and at every place south of it, the south pole dips. And the degree of dip is in general greater as the distance is greater, till at a certain point in the northern hemisphere, and another in the southern, the needle is perpendicular to the horizon. These two places where the needle is vertical, are called the *poles of dip.* The north pole of dip was found by Captain Ross, in 1831, to be at lat. 70° 14′ N., and lon. 96° 40′ W. The south pole has not been accurately located. A line may be supposed to pass through all places where the north pole dips 5°, another where it dips 10°, &c., till the earth is covered with a system of lines somewhat resembling parallels of latitude. These are called lines of *equal dip;* and they are much more regular than the lines of equal declination.

Define *dip*. On what line is there *no* dip? State how the dip changes in going north or south from that line. Define *poles of dip*. Where is the north one? What system of lines relates to this subject?

381. *Magnetic intensity of the earth.*—The strength of the magnetic force is not everywhere the same on the surface of the earth; but in general it increases each way from the equator towards the poles. A line passing through all places at which the force is equal, is called a line of *equal intensity.* And the earth is imagined to be thus covered with a third system of magnetic curves. They pass east and west around the earth, but are not so regular as the lines of equal dip; and in the polar regions they divide into double systems, terminating in *two* poles of greatest intensity in the northern hemisphere, and *two* in the southern. One of the north poles of intensity is near Lake Superior, the other in northern Siberia. The greatest intensity on the earth is nearly three times as great as the least.

382. *The preservation of magnets.*—If magnets are in the form of straight bars, they are best preserved by placing them parallel in a box, with poles in opposite directions, and pieces of soft iron across the ends, as in Fig. 132. These pieces, being magnetized by induction, react on the magnets, and also through them each magnet acts on the other to strengthen it. A single bar magnet is liable to lose some of its power when kept by itself. If the magnet is of the form represented in Fig. 133, called the horse-shoe magnet or the U-magnet, it may be kept by simply laying a piece of soft iron across its ends. The reflex inductive influence operates on each pole to augment its power.

Fig. 132.



383. *The compass.*—This instrument, in its simplest form,

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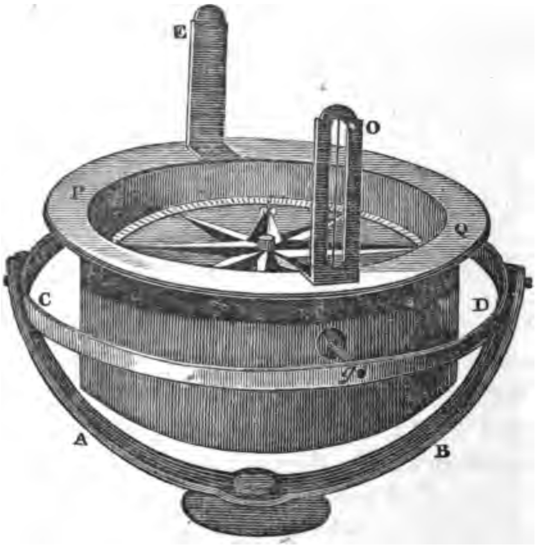
16 Is the strength of magnetism everywhere the same? What is the third system of magnetic lines on the earth? 17 How many north poles of intensity? Where? In what part of the earth is the intensity least? State how straight magnets are preserved. The U-magnet. Describe the compass.

Fig. 183.

consists of a needle suspended in a suitable box covered with glass. This is all that is essential, when it is required merely to know what direction is north or south. But, for most purposes, the compass is furnished with a circular card divided into degrees and minutes; and in the mariner's compass the card is also divided into thirty-two equal parts called *rhumbs*. In the *mariner's* compass, the card is attached to the needle, and revolves with it. The index-mark, which shows the direction of the keel, is a vertical line on the

Fig. 184.



In the mariner's compass, to what is the card attached? How is the box supported?

interior of the box. When any degree of the card is directed to the index-mark, it shows that the ship is sailing in the direction expressed by that degree. To prevent agitation of the needle by the motion of the vessel, it is mounted in *gimbals* (Fig. 134). This contrivance consists of a ring C D, in which the box is suspended by pivots, one of which is seen at *g*, while the ring rests on the pivots C and D, 90° from the former, in the support A B. The lines of the two axes intersect each other in the same point at which the needle is suspended. The box, therefore, remains level, and the needle free to traverse horizontally in every position of the ship.

384. The *Azimuth* compass, and other forms of compass to be used on land, have *sights* or a *telescope* attached to the box, for determining directions on the earth's surface. The card is also fastened, not to the needle, but to the bottom of the box.

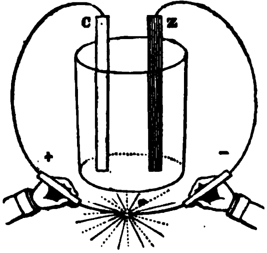
On account of the tendency of the needle to dip at most places, the compass needle must be loaded by a minute weight, which may be adjusted according to the degree of dip. In most northern latitudes, the south end of the needle should be heaviest, and in southern latitudes, the north end.

Describe the *gimbals*. What is attached to the land compass? Why must the needle generally be loaded? State how in different parts of the earth.

PART VII.—ELECTRO-MAGNETISM.

385. *Galvanic electricity.*—When electricity is developed by chemical action instead of friction, it is called *Galvanic* or *Voltaic* electricity, from the names of Galvani and Volta, two Italian philosophers, who made the earliest discoveries relating to this mode of development. The great difference between the galvanic and the frictional electricity is, that the latter is in a state of great intensity (or *tension*, as it is often called), darting violently with noise and light through the air; while the former has very low tension, flowing in a gentle stream through conductors, and unable to pass across interruptions unless they are exceedingly small.

Fig. 135.



386. *The galvanic battery.*—Instruments which are arranged for developing the galvanic electricity in large quantities, are called *galvanic batteries;* but these usually consist of a large number of similar parts, called *elements.* Various forms of elements for batteries have been adopted; one of which, of simple construction, is presented in Fig. 135. A plate of zinc, Z, and one of copper, C, are placed

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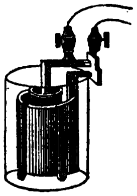
How is galvanic electricity excited? Why so called? How does it differ from frictional electricity? Describe an element of a battery.

in a tumbler of diluted sulphuric acid. Connected with each plate is a wire of indefinite length; and when the ends of these wires are brought into contact, a chemical action commences between the acid and the plates, and a steady flow of electricity passes from the copper plate through the wires to the plate of zinc. The electricity manifests itself in a spark at the place where the wires meet. As soon as the wires are separated, all signs of electricity cease, and are renewed again when the wires are joined. The joining of the wires, by which a communication is formed between the positive pole at the copper, and the negative pole at the zinc, is called *closing the circuit;* and the separation of the wires is called *breaking the circuit.*

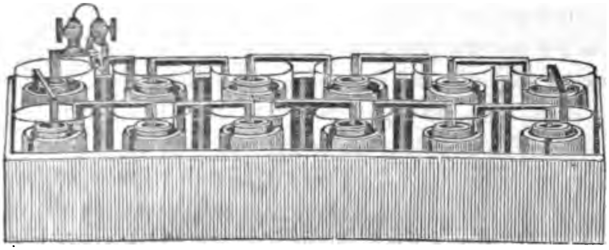
387. *Grove's battery.*—An element of Grove's battery is exhibited in Fig. 136, which represents a glass jar containing a hollow cylinder of amalgamated zinc and mercury, which has a narrow opening on one side from top to bottom. Within the zinc is a cylindric cup of porous earthen-ware, and within that a lamina of platinum is suspended from a cover. One end of the circuit wire is in metallic connection with the zinc, and the other with the platinum, by means of the binding screws at the top. The earthen cup is now filled with strong nitric acid, while the space outside of it, in which the zinc is immersed, contains sulphuric acid diluted with ten times its weight of water. Twelve such elements are represented as combined in a battery (Fig. 137); the zinc of each element being connected with the platinum of the next, from the first to the last.

Fig. 136.



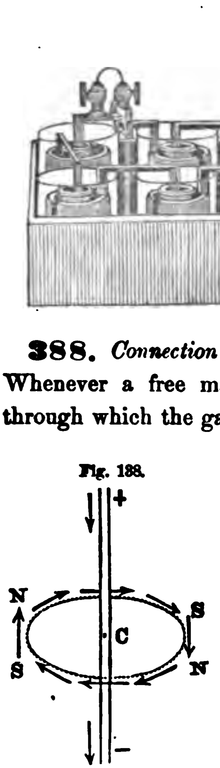
When does the spark show itself? What is meant by *closing* the circuit? *Breaking* the circuit? 2 Describe an element of Grove's battery. 20 How are these elements connected in a battery?

Fig. 137.



388. *Connection of galvanic electricity and magnetism.*—Whenever a free magnetic needle is placed near the wire through which the galvanic current is flowing, it is acted on by the current, and placed in the direction of a tangent to the circle, whose center is in the nearest point of the circuit, and whose plane is perpendicular to the line of the current. Suppose the wire + C — (Fig. 138) is any part of a galvanic circuit, and that the upper end connects with the positive pole of a battery, and the lower end with the negative pole; then the needle will place itself as represented, the point of the arrow in each case being the *north* pole. That is, if the current from the positive pole *descends* through the center C of the dotted circle, the north pole of the needle will point in the direction in which the hands of a watch move, as it lies in the place of that circle. The easiest way in all cases to determine how the needle will place itself, is to conceive of the positive current running through the

Fig. 138.



How is a magnetic needle affected when near the galvanic current? Describe the position of the needle by reference to a clock or watch.

center of a watch or clock face, in the direction in which one *looks* at it, and then the needle, on whatever side it is placed, will direct its *north* pole the same way in which the hands move. Thus, if a clock stands before you, and the positive current moves from you to the center of the face, a needle on the left side throws its north pole *upward*, as the hands, when on the left, move up; if on the right, the north pole points *downward;* if above, toward *the right;* if below, toward *the left.*

389. *Magnetic induction by the galvanic current.*—Not only will the current control the needle, as above stated, but it will *induce* the magnetic state, with poles in the order just described. For instance, if N S (Fig. 138) is a piece of iron wire, showing no sign of magnetic power, yet as soon as a galvanic current flows down the wire +C—, the wire N S will be magnetized by induction, and the end N will become the north pole, and S the south pole. So, if iron filings be scattered on the surface N S, N S, then, as soon as the current descends along the wire, each filing will be a magnet, and their north poles will all lie as shown by the barbs of the arrows, that is, in the direction in which the hands of a watch revolve.

390. *Accumulation of galvanic action.*—When a single current passes near a needle, as already described, its action on the needle is feeble, especially if the current has a low tension. In order that a current of feeble tension may act powerfully on a needle, it is only necessary to let it *continue near* the needle on all sides of it, and pass many times round; then at every point of the circuit-wire the fluid will act on the needle with equal force, and all these actions will conspire together. In this way,

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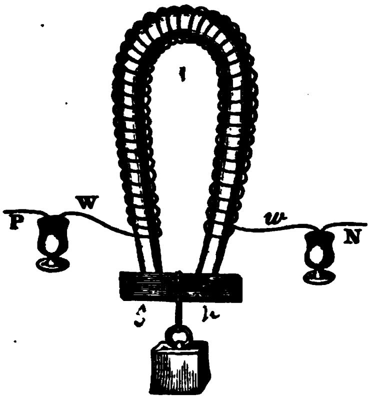
Suppose pieces of iron occupy the places of the needles, how are they affected? Iron filings around the wire? How can the inductive action be greatly increased?

too, a great *inductive* power may be exerted on iron to develop its magnetism. Fig. 139 illustrates the manner of making a magnet of the U form, by the repeated actions of the galvanic current. P is the end of a wire connected with the positive pole of a battery; N the end of another wire from the negative pole of the same. These wires dip into two cups of mercury. A long coil of copper wire passes from one cup around the whole length of the U into the other cup. As represented in the figure, the end W from the positive pole passes just in front of the iron, then behind, and so on around it continually. If the observer suppose himself to stand at W, and to look along the wire in the direction of the flow, he will perceive, that as the iron is on his *left*, the north pole must be thrown *upward*, and the south pole *downward*. In the same way, by following the wire entirely round, the current at *every point* is seen to direct the north pole upward. Thus, every revolution conspires with every other one to carry the north pole over toward *n*, and the south pole down to *s*. The bar of soft iron thus becomes a U-magnet of considerable power, capable of sustaining a heavy weight. The weight is supported by a

Fig. 139.



2H Describe the manner of making a U-magnet. Why is the north pole thrown upward in the figure? How is the weight supported by the magnet?

flat piece of iron called the *armature*, touching the poles below, as represented in the figure. If now the end W, or *w*, is lifted from the cup of mercury, the circuit is broken, the current ceases to flow, and the magnet in an instant loses all its power to hold the weight.

391. If the end W had first passed *behind* the bar of iron, and thus coiled in the opposite direction, it is evident that the north pole would have been directed *downward*, and the south pole *upward;* and in this case, the right hand end of the U would have been the south pole, and the left hand the north pole.

392. To make the magnet as powerful as possible, the coil of wire is closely wound with silk, so that it is insulated, even when coiled as closely as it can be around the U; another layer may then be wound over the first, and any number of layers in succession. The galvanic fluid has so feeble a tension that it will circulate through many thousands of feet, rather than break through the thin laminæ of silk between the spirals of the wire. A large U-magnet may in this way be made powerful enough to sustain hundreds, and even thousands of pounds; but the whole force is lost as soon as the circuit is broken, by taking either end of one of the wires from the cup of mercury.

393. *Electro-magnetism as a motive power.*—Machines can be operated by the electro-magnetic force as truly as by other forces; but as yet this power proves to be much more expensive than steam. Fig. 140 represents one form of electro-magnetic machine invented by Dr. Page. Two electro-magnets of the U form are fastened in an upright position at M and N,

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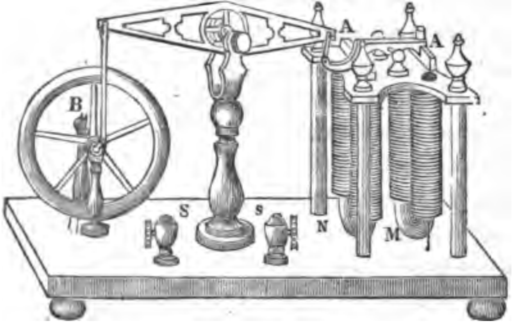
What if either wire be taken out of the mercury? What change in the
wire would place the poles in the opposite direction? What arrangement
26 would make the magnet more powerful still? How great strength may be
produced? Why does not the fluid pass across from one coil to the next?
27 Is electro-magnetism valuable as a prime mover? Why?

having their four poles just in the surface of a table. Above the table is a lever whose fulcrum is between the magnets. The armatures, A and A, are so fastened to the lever, that either may touch the magnet below it, and raise up the other. A projecting part of the lever is attached to the end of a working beam, which gives motion to a fly-wheel by a crank. By means of the binding screws S and S, the coil around either magnet may be connected with the poles of a battery. When the circuit around M is closed, and that around N broken, the right hand armature is attracted to the poles below, and N exerts no attraction to prevent its armature from rising. But the instant after, when the circuit around N is closed, and that around M is broken, the opposite end of the lever descends. Thus, a continued alternation of the lever produces a constant rotation of the wheel. The two circuits are alternately closed and broken by cams on the axis of the wheel.

Fig. 140.



394. *Transmission of the electro-magnetic power.*—That which gives to electro-magnetism its great utility, is the power

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Describe Page's machine. How is the circuit closed and broken? What renders the electro-magnetic power most useful?

of transmitting the current on an insulated wire, so that it shall form a magnet by induction at a great distance from the battery. It was ascertained by Prof. Henry, in 1830, that by means of a battery of many elements, called an *intensity battery*, he could send the current several miles, and cause it at that distance to ring a bell and produce other mechanical effects. He thus proved the possibility of using electro-magnetism for *telegraphic* purposes. It was at first supposed that the current must not only be sent to the distant station on a wire, but also returned on another wire to the other pole of the battery. But, in 1837, it was discovered that the return current could be conveyed by *the earth* or by *water*.

395. *The electro-magnetic telegraph.*—After it was found that the current could produce magnetic motions at a great distance, several plans were devised for communicating telegraphic signals. The one which is generally preferred for its simplicity, is *Morse's electric telegraph.* Suppose that a person at Washington wishes not only to *send* intelligence to Boston, but also to *record* it there, so that it may be read at any time afterward. The person at Washington has under his operating table a battery of so many elements, that its current has sufficient intensity to be transmitted to Boston. From one pole of the battery the wire passes into the earth, and is soldered to a broad copper plate buried in the ground. From the other pole the wire passes up to the table, and is fastened to the binding-screw A (Fig. 141). Another wire is attached to the binding-screw B, and thence extends on insulating supports to Boston. At Boston, this wire passes in a coil around an electro-magnet, and then descends into

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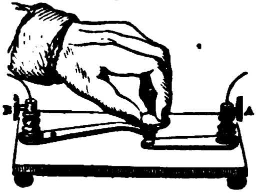
Q When and by whom was this discovered? What kind of a battery is needed? Describe how a person at Washington can move the armature of a magnet at Boston. What apparatus does he need?

Fig. 141.



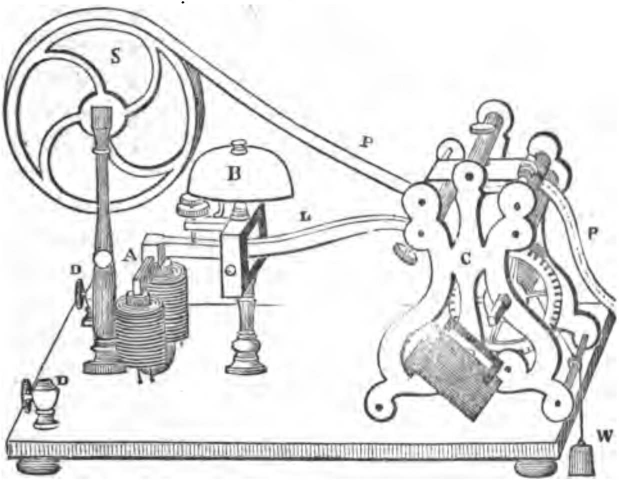
the ground, and is soldered to a buried plate of copper. Between this copper plate in Boston and the one in Washington, the galvanic current can pass back to the battery through the earth. The circuit is now complete, except a little break (Fig. 141) under the operator's hand in Washington. If he presses down the key in contact with the metallic bar beneath it, the entire circuit is closed, and the current from one pole of the battery in Washington is transmitted to Boston, then hundreds of times around the U-magnet there, then into the ground, and thence back in the earth to the other pole of the battery, all in a small fraction of a second. While it circulates through the coil of the magnet in Boston, it induces the magnetic power, and causes it to attract the armature above it. But if the operator ceases to press on the key, a spring throws it up and breaks the circuit, and instantly the magnet in Boston loses its power to hold down the armature, which is at once raised by a spring. Thus an individual in Washington can control the movements of the armature in Boston as perfectly as if it were under his hand.

396. *The recording instrument.*—Let us next see what is accomplished by the movement of the armature in Boston. Fig. 142 represents the recording instrument of Morse's telegraph. The armature A is situated above the poles of the magnet, and attached to one end of the lever L; on the other end is the *style*, a blunt metallic point for recording the movements.

How is the fluid conveyed back? Where is the only interruption in the circuit? What happens if he presses the key down? Why does the key rise when he ceases pressing? What happens then? Describe the *recording* instrument.

Whenever the circuit from Washington is closed, A is attracted to the magnet, and the style is pressed upward against a strip of paper P P, which is carried round a roller at that point by the action of clock-work. The roller has a small groove around it at the place where the style presses, so that it indents the paper into the groove. If the operator strikes the key, and instantly removes the finger, the style merely indents a *dot* in the paper; if he continues the pressure a moment, the paper is drawn along, and the indentation becomes a *line*. An alphabet is formed of dots and short lines, variously combined, as shown in the following table, which the operator learns to use with

Fig. 142.



Show what takes place at Boston when the key at Washington is depressed. Again, when it rises. How is a *dot* made? How a line? Why is there a groove in the roller? What kind of alphabet is used?

rapidity in spelling the words of a message, and the record is permanently stamped on the paper.

MORSE'S ALPHABET.

a - —
b — - - -
c - - -
d — - -
e -
f - — -
g — — -
h - - - -
i - -
j — - — -
k — - —
l ——
m — —
n — -
o - -
p - - - - -
q - - — -
r - - -
s - - -
t —
u - - —
v - - - —
w - ——
x - — - -
y - - — - -
z - - - -

397. Those who are accustomed to the work of sending and receiving telegrams, soon acquire the power of distinguishing the letters by the ear, and can therefore understand a communication without looking at the record. W is the weight that moves the clock, or the motion may be given by a spring. The only purpose of the clock-work is to draw along the paper over and under a series of rollers from the reel S, keeping it always stretched upon the groove where the style strikes it. The machine may be so made that the first stroke on the key at Washington will ring a bell B, and call attention to the telegram about to be transmitted. D, D, are the binding-screws by which the wire from Washington, and that from the buried copper plate in Boston, are connected with the two extremities of the helix around the magnet.

The same circuit will serve to convey telegrams back from

Can a telegram be read by the ear? The use of the clock? How can telegrams be sent back?

Boston to Washington, if the operator in Boston has a battery, and the one in Washington a recording instrument.

398. *Action of galvanic currents on each other.*—If wires, through which currents are flowing, are placed near and parallel to each other, there is a mutual action between them; if the currents run in the *same* direction, the wires *attract*, if in *opposite* directions, they *repel.* It follows, that when a current is flowing through a loose coil, whose spires are free to move, each spire attracts the next, and the whole coil is shortened by means of this attraction. Also, if the end of one coil is brought to the end of another, they will attract when the circulations are in the same direction, and repel when they are opposite. On the discovery of these facts, Ampere, of France, formed the theory that all magnetic phenomena result from the attraction of galvanic currents, circulating in the magnets as in coils from one pole to the other.

399. *Magneto-electric phenomena.*—In accordance with the theory of Ampere, it might be expected that a magnet would develop an electric current in a coil. And this was found to be a fact. If a hollow coil prepared for the electro-magnet is connected with a *galvanometer* (a delicate instrument for measuring the strength of the galvanic current), and a bar-magnet be quickly thrust within the helix, and then withdrawn, the needle of the galvanometer will be deflected; and if the opposite pole be inserted, the needle will be deflected the opposite way. The name *magneto-electricity* has been given to the electric currents when caused by the action of the magnet. Whenever a magnet is set revolving near a plate of copper, feeble currents

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How do wires affect each other when currents are passing through them? The effect of a current through a free coil? What is a magnet, according to 30 Ampere's theory? Does a magnet excite galvanic currents? Describe the experiment to prove it. 31 What is *magneto-electricity?*

are excited in the copper, and, if the plate is free to move, it will soon begin to rotate in a parallel direction. Or, on the other hand, if the plate is revolved, a magnetic needle suspended over it will gradually acquire the same motion, in consequence of currents excited in the copper by the needle. The magnet also excites currents in other substances, though in a less degree than in copper.

400. *Thermo-electricity.*—Electrical currents are also excited by *heat;* and in that case the development is called *thermo-electricity.* Bismuth and antimony are the best materials for exhibiting phenomena of this kind. The magnetism of the *earth* may be attributed to the electrical currents which the heat of the sun excites, and which continually circulate from east to west, as the earth revolves on its axis.

401. *Electrical fishes.*—There are three kinds of fish which possess the power of giving the electric shock, the most interesting of which is the electrical eel of South America. The electrical organs in these animals resemble the voltaic pile in their construction. The currents produced by them affect the galvanometer, and may be made to give the electric spark. The fishes exercise this power voluntarily, for the purpose of paralyzing their prey when pursuing it, and also as a means of self-defence.

Describe experiments with a magnet and disk of copper. What is *thermo-electricity*? How may the magnetism of the earth be explained? Give an account of electrical fishes. Of what use is their power?

PART VIII.—OPTICS.

CHAPTER I.

LIGHT.—ITS MOTION AND INTENSITY.

402. *Definitions.*—Optics is the name of that branch of Natural Philosophy which treats of light and vision. *Light*, according to the theory now generally received, consists of exceedingly minute and rapid vibrations in a medium or ether which fills space; which vibrations, on reaching the retina of the eye, cause vision, as the vibrations of the air cause hearing, when they fall on the tympanum of the ear.

403. Bodies which of themselves are able to excite vibrations in the surrounding ether, are said to *emit* light, and are called *luminous* bodies; those which only *reflect* light are called *non-luminous.* Most bodies are of the latter class. A *ray* of light is a line along which light is propagated. A *beam* is made up of many parallel rays; a *pencil* is composed of rays either diverging or converging, and is sometimes applied instead of the word *beam* to parallel rays. A *radiant* is a point from which light diverges; a point to which rays converge is called a *focus;* but the word *focus* is often used in general to denote the point of intersection of several rays, whether diverging or converging.

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1 Of what does *optics* treat? 2 What is light, according to the common theory? 3 What bodies are said to *emit* light? What are they called? What are other bodies called? Define *ray; beam; pencil; radiant; focus.*

A *medium* is any substance through which light can pass; if objects can be clearly seen through the medium, it is called *transparent;* if dimly seen, *semi-transparent;* if only the light is discerned through a medium, and not the objects from which it comes, it is said to be *translucent.* An *opaque* body is one through which no light can pass.

404. *Light moves in straight lines.*– So long as the medium continues uniform, the line of each ray is perfectly straight. An object cannot be seen through a bent tube. The edges of shadows, as they stretch through smoky air, are seen to be straight; a good example often occurs in the sunbeams visually projected on clouds. On account of the straightness of rays, pencils of light and also shadows have certain regular geometrical forms; thus, if light, radiating from a point, passes through a circular opening, the pencil is a cone; if through a square aperture, it is a square pyramid, &c.

405. *The velocity of light.*—It has been ascertained by several independent methods, that light moves at the rate of about 192,500 *miles per second.* One method is by means of Jupiter's satellites. Some of them are eclipsed by Jupiter at every revolution; and by the average interval which is observed between the eclipses of any satellite, the times of their occurrence can be predicted. Now, it always happens, that when we are *nearest* to Jupiter, an eclipse occurs about 8¼ minutes sooner than the time calculated; and when we are *furthest off*, it occurs as much too late. It therefore requires about 16½ minutes for light to cross the earth's orbit; and as the distance is 190,000,000 miles, it must travel with the velocity above mentioned.

Describe the different ***media.*** **Give proofs that light moves in straight lines. Example in sun-beams. Name the form of a pencil from a point, and passing through a circular aperture. A square aperture, &c. What is the velocity of light? State the first method of finding it.**

406. The velocity of light is also determined by the *aberration of the stars*, which is an apparent annual displacement, resulting from the earth's motion combined with the motion of light. The impulse of the light from the stars upon our eyes, is in a direction slightly different from what it would be if we were at rest; just as rain-drops strike one's face a little differently when running and when standing still. The velocity of light from a lamp has also been obtained by direct experiment. By each of these methods the velocity is found to be the same.

407. *Loss of intensity.*—As light, in radiating from a body, becomes more and more widely diffused, its intensity is constantly diminished. If a pencil, diverging from a point and passing through a square aperture, proceeds to an equal distance beyond, it covers a square twice as wide each way, that is, *four* times as large, and is therefore *four* times less intense. So, in proceeding *three* times as far, it becomes *nine* times less intense. Therefore, by mere diffusion over greater spaces, *the intensity of light varies inversely as the square of the distance.*

But if light passes through any medium, some of it is absorbed, and some reflected by the medium itself, and therefore it loses intensity the farther it proceeds on this account also. Thus, the light which the stars shed upon us is diminished by coming through the atmosphere.

408. *Shadows.*—The shadows of spherical bodies, cast by a spherical luminary, are either cylinders or cones. These shadows are of two kinds, *total* and *partial.* By supposing tangents

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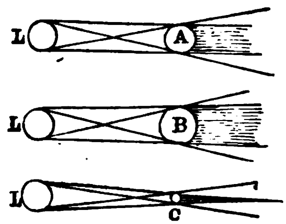
What is the second? Illustrate it by rain. A third method? If a diverging pencil proceeds *twice* a certain distance, how many times larger space will it cover? *Three* times the distance, how large? Give the law of intensity as to distance. In what other way does light lose intensity? Example. How many kinds of *shadows* are there?

drawn across the *corresponding* sides of the two bodies, we determine the limits of the total shadow; for it is plain that no ray can pass within these tangents beyond the opaque body. If the bodies are equal, as L and A (Fig. 143), the total shadow is a cylinder of infinite length; if the luminous body is the smaller, as L and B, the total shadow is an increasing frustum of a cone of infinite length; if the luminous body is the larger, as L and C, the total shadow is a cone, whose base is a section of the non-luminous body. The partial shadow or *penumbra* is limited by tangents drawn to touch *opposite* sides of the bodies. The form of the penumbra is an increasing frustum of a cone. It is obvious that a part of the light from L can, in each case, pass within these diverging tangents, and that the depth of shade increases from the outer limit to the total shadow. All shadows of terrestrial bodies cast by the sun or moon, are surrounded by a perceptible penumbra, so that the projected shadows are not sharply defined on their edges, but shade off gradually from the total shadow to the full light.

Fig. 143.



409. As the luminary becomes smaller, the penumbra surrounding the total shadow is thinner; and when it becomes a point, the penumbra ceases, and the total shadow is sharply defined. The same effect is produced if the luminary is more dis-

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What lines limit the total shadow? If the bodies are *equal*, what is the form? If the luminous body is the smaller? If larger? What lines limit the penumbra? Its form? Do terrestrial bodies cast shadows with a penumbra, when the sun or moon shines on them? What if the luminous body were a point?

tant till it *appears* as a point. Thus, the shadows cast by a star, if perceptible, are without a penumbra.

CHAPTER II.

REFLECTION OF LIGHT.

410. *Definitions.*—Light is said to be *reflected* when it is thrown back from a surface into the same medium again. From ordinary surfaces, the reflected light is scattered in all directions. This is *radiant reflection;* and it is by means of it that we see objects which shed no light of their own. But when a surface is highly polished, a beam of light falling on it is reflected in a certain determinate direction; and, if the eye is placed in this reflected beam, we see, not the reflecting surface, but the original object, apparently in a new position. This is called *specular reflection,* because produced by a speculum, or ground metallic mirror. In ordinary mirrors a lamina of mercury and tin forms the reflecting surface, which receives its polish from the glass to which it adheres. Three forms of mirror or speculum are used in optics: the *plane,* the *convex,* and the *concave.* Experiments on light are usually performed in a darkened room, by receiving a sunbeam through an aperture from an adjustable speculum on the outside.

411. *Law of reflection.*—When a ray falls on a surface, the angle between it and a perpendicular to that surface is called the *angle of incidence,* and the angle between the reflected ray

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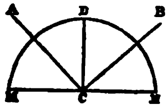
What if its distance were as great as that of the stars? When is light said to be *reflected?* What is *radiant* reflection? Its use? What is specular reflection? What forms of mirror are used in optics? State the *law* of reflection. Define the angles of *incidence* and *reflection.*

and the same perpendicular, the *angle of reflection.* It is found by observation to be always true, that *the angles of incidence and reflection are in the same plane, and are equal to each other.*

412. This may be shown by attaching a small mirror to the center of a semicircular board, perpendicular to its plane. Let Fig. 144 represent the semicircle, graduated from D each way to M and N. If a ray A C passes the edge at a certain degree, the reflected ray C B will be seen to pass the corresponding degree on the other side of the perpendicular C D. By revolving the semicircle, every angle of incidence may be tried. When the incident ray is perpendicular to the mirror, the reflected ray returns in the same line, each angle being zero.

Fig. 144.



413. Radiant reflection forms no exception to the foregoing law, although the incident light is in *one* direction, and the reflected light is scattered every way; for it is produced by *roughness* of surface. The little inequalities present their minute surfaces at all inclinations; and each individual ray is reflected according to the law, and yet the whole beam becomes scattered in all possible directions.

414. *Relation of rays preserved by the plane mirror.*—When a pencil is reflected by a plane mirror, the rays of the pencil maintain the same relation to each other after reflection as before. That is, if the incident rays are *parallel*, the reflected rays are parallel; if the incident rays *diverge* or *converge*, the reflected rays also diverge or converge at the same angle.

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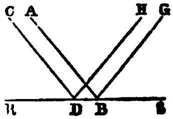
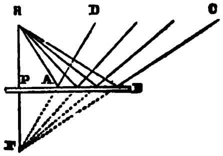
15 Describe the way of showing the law. How is a ray reflected, if it falls perpendicularly on a mirror? 16 What is the cause of radiant reflection? How can the *law* apply in this case? 17 In reflection from a plane surface, compare the relation of rays *before* and *after* reflection. State particular cases.

Fig. 145.



415. Thus (Fig. 145), the incident rays A B, C D, being parallel, the reflected rays D H, B G, are parallel also. And (Fig. 146) the diverging pencil R A, R B, will, after reflection, continue the same degree of divergency, in the lines A D, B C, just as though they had radiated from F, as far behind the mirror as R is before it, and in the same perpendicular R F. And again, the converging pencil D A, C B, proceeding toward F, will be reflected to R, converging just as rapidly as before. The reason in each case is this: the perpendiculars at the several points of reflection are *parallel* lines; hence, as the reflected rays have the same inclination to the perpendiculars which the incident rays have, they will be inclined to *each other* just as much as the incident rays are.

Fig. 146.



416. The point R, from which the light radiates, is the *real* radiant; but F, from which the reflected rays seem to radiate, is called the *apparent* or *virtual* radiant. So, when converging rays, proceeding toward F, are reflected by the mirror, and meet at R, F is the *apparent* focus, R the *real* one.

417. *Images by the plane mirror.*—As every point in the surface of a visible object, throws off rays of light in all directions, every such point is a *real* radiant. On the other hand, an image formed by the plane mirror is made up of *apparent* radiants. And, as each apparent radiant is as far behind the mirror as the object

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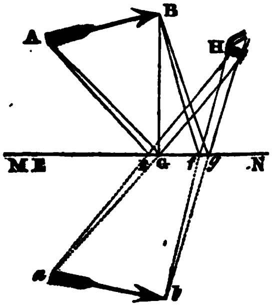
18 Illustrate by figure. State the general reason. 19 Show the distinction between the *real* and *apparent* radiant. 20 Also real and apparent focus. Of what is a visible object made up? 21 The image in a plane mirror is composed of what?

is before it, the same must be true of the entire image. These apparent radiants being all accurately arranged behind the mirror, to correspond with the real ones before it, an observer seems to see the object itself in a new position. Thus (Fig. 147), the object A B, before the plane mirror M N, forms its image *a b* equal to A B, and at an equal distance behind the mirror. For, as the point A radiates light in every direction, a certain pencil A F G, after being reflected, and reaching the eye at H, appears to have radiated from *a;* and B *f g* arrives at H, after reflection, as though from *b*. And, in like manner, every point of A B has a corresponding point in *a b*. If the position of the eye is changed, the image will be seen by a different system of pencils, but the effect will be the same, and the place of the image will not be altered.

Fig. 147.

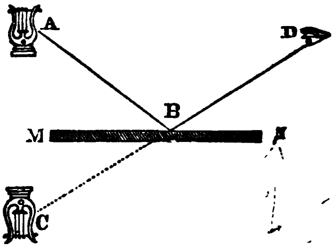


418. The image is not similar to the object, but *symmetrical* with it; that is, one and only one of its three dimensions is *inverted*, namely, the one perpendicular to the mirror. Thus, if a person before a mirror faces the *north*, his image faces the *south;* but there is no other inversion, either vertical or lateral. Again, if a mirror is horizontal, as the smooth surface of a lake, trees and other objects are seen with the tops downward, since it is the vertical dimension which is perpendicular to the mirror.

Where is the image formed by a plane mirror? How situated? Of what size? If the place of the eye is changed, is the image seen by the same pencils? Is the image itself changed? Is the image *similar* to the object? What dimension is inverted? Give examples? Person before a mirror. Trees seen in a lake.

An illustration is seen in Fig. 148, where the *erect* harp is seen as an *inverted* harp below the horizontal mirror. The reason why an image has the *right* hand correspond to the person's *left* hand, is not because there is a *lateral* inversion,. but because right and left change places with each other, whenever a person turns his face in the opsite direction, as the image does.

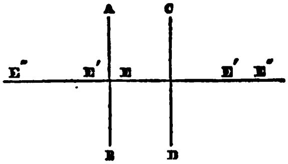
Fig. 148.



In order that a person may see his entire image, the mirror needs to be half as high as himself.

419. *Multiplied images by two mirrors.*—If the mirrors are *parallel*, as in Fig. 149, and the object E lies between them, then its image in A B is E′, as far behind as E is before it; now E′ may be regarded as an object in front of C D, and its image formed by C D is E″, as far to the right as E′ is to the left of it; and the image of E″ formed by A B is E″ at the left, and so on. Beginning again with the mirror C D, there will be another series of images, the first of which is E′ behind C D, and so on, as before. All these images, infinite in number, are arranged in a straight line, perpendicular to the mirrors; but

Fig. 149.



How do *right* and *left* become inverted in the image? How high a mirror is needed to see the whole person? Explain the effect of two parallel mirrors. What is the number of images?

they grow more faint at greater distances, by loss of light at every reflection.

420. In order to understand how an *image* at E′, which is *nothing* in reality, can serve as an *object*, and have an image of itself formed in the opposite mirror, it should be considered that the light radiating in all directions from the object E, when it has been reflected by A B, diverges just as though it had originated in E′; and when these rays come to impinge on C D, it is immaterial whether they *actually* came from E′ or only proceed *as if* they came from it. A new image is formed equally well in either case. Multiplied images of a lamp are sometimes seen in a looking-glass, when viewed at a large angle of incidence, the light being reflected back and forth between the front and back sides of the glass. And, in the same manner, a bright star or planet, when viewed in a mirror, appears attended by three or four faint images of itself.

421. If the mirrors are *inclined* to each other, then the images of an object placed between them are arranged in the circumference of a circle, whose center is in the common section of the mirrors. The *kaleidoscope* furnishes a beautiful illustration of this case. In order that the symmetry of the picture formed by the objects and their repeated images in this instrument may be perfect, the angle between the mirrors must be such that 360° divided by it will give an *even* number for a quotient. The best angle is 30°, in which case the picture will be distributed in twelve sectors, since 30° is $\frac{1}{12}$ of 360°.

422. *The converging effect of a concave mirror.*—When rays of light are reflected by a *curved* mirror, they do not preserve to

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How can an *apparent* image serve as an object? Explain how multiplied images are seen in a looking-glass. How are the images arranged when the mirrors are inclined? What example is named? Describe. Do *curved* mirrors preserve the relations of the rays?

each other the same relation before and after reflection, as they do in the case of a *plane* mirror. If the mirror is *concave*, the reflected rays are always turned more *toward each other* than the incident rays; so that *parallel* rays become *converging; converging* rays become *more* converging; and *diverging* rays become at least *less* diverging, and may become *parallel*, and even *converging*.

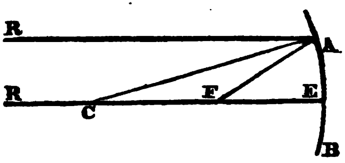

Fig. 150.

423. Fig. 150 shows the case of parallel rays R A, R E, falling on the concave spherical mirror A B. Let C be the center of its concavity, then every radius, C E, C A, &c., is perpendicular to the surface of the mirror. Since R E strikes perpendicularly, it is reflected directly back; but any other ray, R A, is reflected on the other side of C A, making the angles R A C, C A F, equal to each other. Hence, the reflected rays E F, A F, converge to the point F. If the mirror is only a very small part of the spherical surface, as it always is in optical instruments, then F is half way from E to C. This point F, being the focus to which parallel rays are converged, is usually called the *principal focus*. Therefore, *the principal focus of a concave mirror is midway between the center and the surface.*

424. If the incident rays diverge from any point further from the mirror than the principal focus, the reflected rays will converge. Thus (Fig. 151), if the radiant is A, beyond the center C, the angle of incidence A B C equals the angle of reflec-

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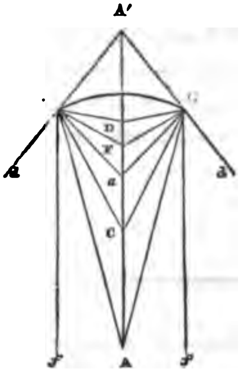
26 What is the effect of a concave? Case of *parallel* rays. Trace the rays.
27 Where is the focus? Describe the several cases in Fig. 151.

tion C B *a*, and *a* is the focus of rays from A. Also, if *a* is the radiant, A is its focus. Hence, A and *a* are called *conjugate foci;* and for every point more remote from the mirror than its center C, there is a conjugate focus between C and F. Since a ray passing through the center is always reflected directly back, any pair of conjugate foci are in the same radius, or radius produced. If the radiant is at C, its conjugate focus is there also, because each ray from C strikes the mirror perpendicularly, and returns to C. If light diverges from a point nearer the mirror than the principal focus, as D, it still diverges after reflection, but less than before; thus, D B, D G, diverge in the lines B *d*, G *d*, and the apparent radiant is A′. On the other hand, if the incident rays converge, as *d* B, *d* G, the reflected rays converge more, and meet at some point D, nearer than the principal focus.

Fig. 151.



425. *Images by the concave mirror.*—The concave mirror forms various images, either *real* or *apparent*, either *erect* or *inverted*, either *greater* or *smaller* than the object, either *before* or *behind* the mirror, according to the distance of the object.

1. The object *nearer the mirror than its principal focus.*—In Fig. 152, let C be the center, F the principal focus, and A B the object. It has been shown (Art. 424) that the reflected light *diverges*, though less than before reflection. Therefore, the

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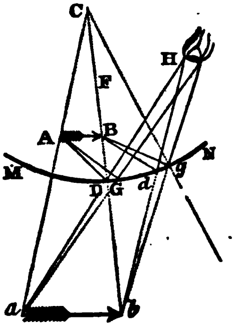
Explain *conjugate foci.* What variety in the *images* of a concave mirror? Describe the image formed, when the object is nearer than the principal focus.

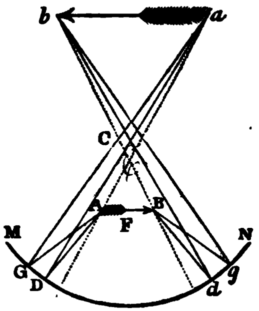
image is *behind* the mirror, as *a b;* and being composed of apparent radiants, it is called an *apparent* image. It is *erect,* since the conjugate foci, A and *a*, are in the same radius produced, as also B and *b;* and these radii do not cross each other between the object and image. The image is also *larger* than the object, because it fills the same angle at C at a greater distance. If the object is at F, the rays of each pencil become *parallel* by reflection, and therefore the image is infinitely distant, and is viewed as a heavenly body.

Fig. 152.



2. The object *between the principal focus and center.*—Let A B (Fig. 153) be the object. Then the rays from A are *converged* to *a* in the same radius produced; likewise those from B to *b*. Thus, all the points of A B have their conjugate foci in *a b*. But the rays do not stop at those points, but cross each other and diverge again. Hence, a person beyond *a b* receives the rays from it as if it were an original object, and sees it in the air between himself and the mirror. The image is therefore *real*, and *in front of* the mirror. It is also *inverted*, because the extreme radii or axes, A *a*, B *b*, cross each other between the object and image. And

Fig. 153.



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30 Between focus and center.

finally it is *magnified*, being as much greater than A B, as it is more distant from C. As the object approaches C, the image likewise approaches it, and they both reach it together, but do not coincide, since the image remains inverted.

3. The object *beyond the center of concavity*.—The same figure (153) will illustrate this case also. Let *a b* be the object, then A B will be its image *before* the mirror, *real*, *inverted*, and *diminished*.

426. All these cases may be shown by moving a lamp along the axis of a mirror, between it and the spectator. While the lamp is nearer the mirror than the principal focus, the image is behind and enlarged. As it recedes, the image at length appears in the air before the mirror, and inverted. Or it may be received on a piece of white paper, held at the proper distance. A person may also see the image of his own face inverted, between himself and the mirror, when he is more distant than the center.

427. *The concave mirror a burning-glass.*—Since heat is reflected according to the same law as light, a concave mirror will converge both heat and light from the sun into the same image at the principal focus. The heat may be thus rendered so intense as to inflame bodies. The amount of heat thus collected depends on the size of the mirror, and the solar image.

428. *The diverging effect of a convex mirror.*—Let M N (Fig. 154) be a convex mirror whose center of convexity is C.

Parallel rays are reflected *diverging*. For while the ray A D is reflected directly back, A M is reflected on the opposite side

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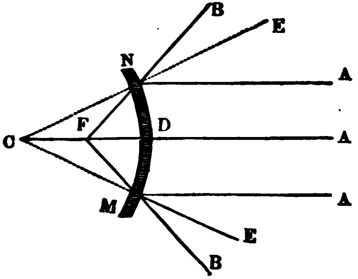
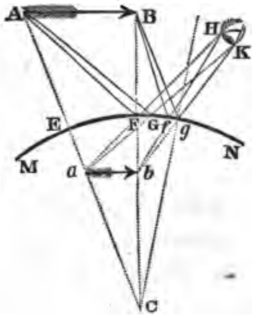
Beyond the center. How are all these illustrated? Describe. Why is the concave mirror a *burning* glass? What is the effect of a *convex* mirror? Effect on *parallel* rays?

Fig. 154.



of C E, making B M E equal to A M E; so A N takes the direction N B, and the rays diverge as from F. If the mirror is a small part of the surface of a whole sphere, F is the middle point between C and D. If parallel rays are rendered divergent, it follows that *diverging* rays are made still *more divergent;* and that *converging* rays are at least made *less convergent*, perhaps *parallel* or *divergent.* The convex mirror, therefore, always produces the effect of separating the rays.

Fig. 155.



429. *Images by the convex mirror.*—The convex mirror furnishes no such variety of cases as the concave, because the rays, diverging from an object, are made to diverge still more by reflection. In Fig. 155, the pencil from A is reflected as if radiating from *a*, in the same axis A C, and that from B, as from *b* in the axis B C. The image is therefore *behind* the mirror, *apparent*, *smaller* than the object, because nearer the angle C, which they both subtend; and *erect*, as the axes do not cross between the object and image.

430. *Spherical aberration of curved mirrors.*—When a

On *diverging* rays? On *converging* rays? 37 Describe what kind of *image* the convex mirror forms.

plane mirror is used, all the rays emanating from one point of the object are reflected so as to diverge accurately from the corresponding point of the image. But this is not true of a spherical mirror, especially if it is any considerable portion of a hemisphere. The rays reflected near the edge of the mirror deviate somewhat from those reflected near the center. In the concave mirror, when used to form a real image, the outer rays converge a little too much. On this account, the image is imperfect, since the rays from one point of the object are diffused over adjacent points in the image. This deviation is called *spherical aberration.* It cannot be entirely prevented, except by grinding the outer parts to a less degree of curvature than the center, which changes the mirror from a spherical to a spheroidal form.

CHAPTER III.

REFRACTION OF LIGHT.

431. WHEN light falls on a body, some part of it is always *reflected.* If the body is transparent, another part is *transmitted;* but this is usually bent out of its course as it enters, and again as it leaves the body. This deviation from a straight line, in passing from one medium to another, is called *refraction.* If the medium which the light enters is *more dense* than the other, the rays are usually refracted *toward* the perpendicular to the

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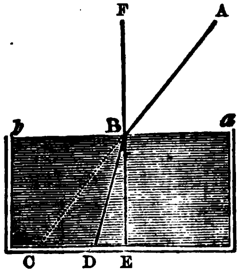
State how the rays reflected from the *edge* of a concave mirror compare with those from the *central* part. What is this deviation called? What evil results? How is it prevented? How is transmitted light commonly affected? What is this change called?

surface; when light passes into a *rarer* medium, it is refracted *from* the perpendicular. Thus, if A B (Fig. 156) passes out of air into water, through the surface *a b*, instead of proceeding in the straight line A B C, it is bent into B D, *toward* the perpendicular F B E. And if the ray D B goes from water into air, it is bent *from* B F into the line B A.

Fig. 156.



432. The angle between the incident ray and the perpendicular is called the *angle of incidence;* the angle between the refracted ray and the perpendicular, the *angle of refraction.* Thus, when A B is turned into the direction B D, A B F is the angle of incidence, and D B E the angle of refraction.

433. The refraction of light is illustrated by many familiar facts. As we look obliquely into a vessel filled with water, the bottom is seen very much elevated, because the rays which come from the bottom over the edge are bent *from* the perpendicular, that is, downward, and reach the eyes as if they came from higher points. So, if a stick is held obliquely in water, the immersed part appears bent *upward,* since the light coming from it, is bent downward at the surface of the water. It is for this reason that water, even when we look perpendicularly into it, appears more shallow than it really is. For the rays of each pencil coming up from the bottom, and entering the pupil of the eye, become more divergent by being refracted from the perpendiculars, and appear to radiate from points about one-fourth

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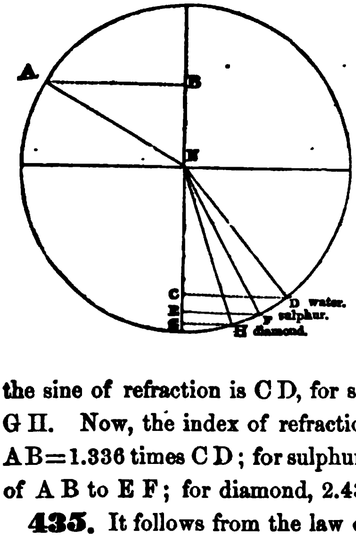
36 What is the general law? Define the angles. 37 Give examples of refraction. Bottom of a vessel full of water. A stick. Depth of water.

nearer the surface. Hence, when water is *four* feet deep, its apparent depth is only *three* feet; and, if we look obliquely into it, even much less than that.

434. *The law of refraction.*—When a ray of light enters a medium, if the angle of incidence is changed, the angle of refraction is changed also, but not in the same degree. The law for these changes is this: *the sine of incidence and the sine of refraction have to each other a constant ratio.* The *index of refraction* for any substance is this ratio of the sines of incidence and refraction, and is used as the measure of the refractive power of that substance. Fig. 157 shows the degree of refraction of three different substances, *water*, *sulphur*, and *diamond*. If A B is the sine of incidence, then for water the sine of refraction is C D, for sulphur it is E F, for diamond G H. Now, the index of refraction for water is 1.336; that is, AB=1.336 times C D; for sulphur it is 2.148, which is the ratio of A B to E F; for diamond, 2.439, the ratio of A B to G H.

Fig. 157.



435. It follows from the law of refraction, that light cannot always escape from a denser to a rarer medium. If the medium above R S (Fig. 158) is more dense than that below it, and A C is bent from the perpendicular into C E, then, on increas-

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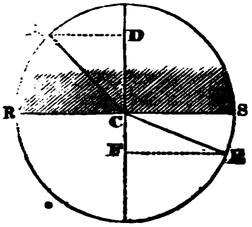
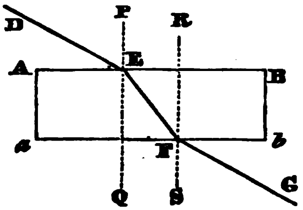
What is the law of refraction as to change of inclination? Define the *index of refraction*. Apply in case of water, sulphur, and diamond. In what case can light not pass through a surface?

Fig. 158.



ing the angle of incidence, C E will approach nearer C S, and at length will reach it, after which the ray can no longer emerge from the dense medium. At that moment the whole beam is *totally* reflected from the internal surface. This mode of reflection is sometimes employed where it is important to prevent loss of light. The greater the refracting power of a substance, the sooner does the incident ray reach the limit of total reflection.

Fig. 159.



436. *Transmission through plane surfaces.*—If the plane surfaces of a medium are *parallel*, as in Fig. 159, then a ray D E is bent *toward* a perpendicular of the first surface on entering, and again *from* a perpendicular in leaving. And as these perpendiculars are parallel to each other, the two refractions are equal, and the *emergent ray is parallel to the incident ray.* It is for this reason that objects are seen in their true forms and positions when viewed through good window-glass. The distortions produced by poorer kinds of glass are owing in part to unequal densities, and in part to irregular curvatures in the surfaces.

437. If the plane surfaces, through which the light passes, are inclined to each other, the medium is called a *prism*, and

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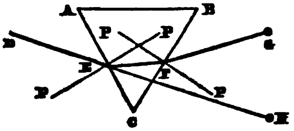
What takes place when light reaches this limit? How is light affected in going through a medium with *parallel* surfaces? Why? Why do objects sometimes appear distorted when seen through a window? What is a *prism?*

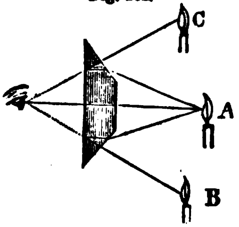
the edge at which the surfaces meet, is the *refracting angle* of the prism. A beam, in passing through a prism, *is refracted away from the refracting angle.* Thus (Fig. 160), A B C is a section of a prism; and if the light passes through the surfaces A C and B C, C is the refracting angle. But A or B may be used for the refracting angle as well as C. The ray D E is first refracted *toward* the perpendicular E P, and traverses the prism in the line E F. On leaving, it is bent *from* the perpendicular F P, and emerges in the line F G, being in each case turned from the refracting angle.

Fig. 160.



438. The medium may have many plane surfaces, so that the light shall be refracted into a number of separate beams. The *multiplying glass* (Fig. 161) is an example. The light radiating from A goes perpendicularly through the center facet, and shows the object in its true direction; that which falls on the upper facet is bent from the upper refracting angle, and reaches the eye as if from C; that through the lower, as if from B, and so on, according to the number and inclination of the facets. A glass cut in this manner often has as many as twenty facets, and causes a small object, as a coin, to appear like twenty such objects. The two surfaces, through which any one pencil of light passes, may be considered as forming a prism.

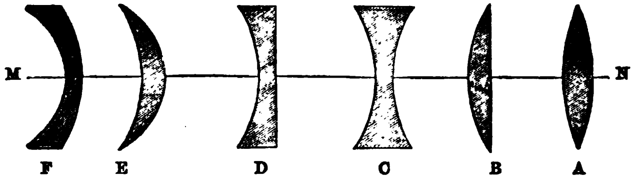
Fig. 161.



Which way is the light turned? Explain. Describe the *multiplying* glass, and its effect.

439 *Trnasmission through curved surfaces.*—In practical optics, great use is made of the *lens*, which is a circular piece of glass, having one or both of its surfaces *curved.* The various combinations of surface are exhibited in Fig. 162.

Fig. 162.



The *double-convex* lens, A, has two convex surfaces.

The *plano-convex* lens, B, has a plane and a convex surface.

A *double-concave* lens, C, has both surfaces concave.

A *plano-concave* lens, D, has a plane and a concave surface.

The *meniscus*, E, has a convex and a concave surface, the convexity being greater than the concavity.

The *concavo-convex* lens, F, has a convex and a concave surface, the concavity being greater than the convexity.

The axis of a lens is a straight line perpendicular to both surfaces, and usually passes through the center of the lens, as M N.

440. Three of these forms, A, B, and E, are thicker at the center than at the edge, and produce a *converging* effect upon light, refracting the rays away from the edge towards the axis. The other three, C, D, and F, are thinner at the center than at the edge, and produce a *diverging* effect, turning the rays away from the axis.

441. Fig. 163 explains the converging effect of a convex lens. Suppose C to be the center of the right-hand surface, and

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Describe the *lenses.* Which converge light? Which diverge it? Show by a figure how a convex lens *converges* light.

C′ of the left-hand, and that a pencil of light radiates from R, covering the whole lens. Then the ray R L proceeds without refraction, since it meets the surface perpendicularly. But any other ray, as R G, is first bent *toward* the perpendicular G C′, and therefore toward the axis R F. When the ray leaves the lens at H, it is refracted *from* the perpendicular C P′ and therefore still more toward the axis, as in the line H F. All forms of lens, which have excess of convexity, act on the rays in a similar manner. But in a *concave* lens, the center of concavity lies on the same side with the surface, and therefore the rays are bent in the opposite direction, that is, *away* from the axis.

Fig. 163.

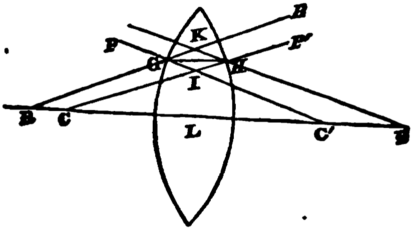
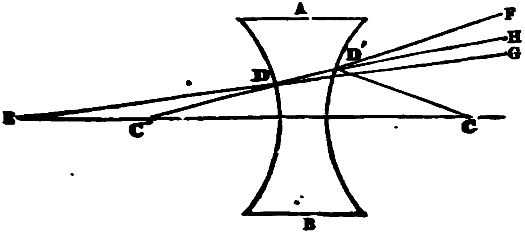


Fig. 164.



Thus (Fig. 164), the ray E D is first refracted *toward* C′ D pro-

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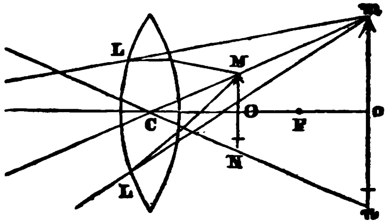
Describe the effect of a concave lens by using the figure.

duced, into the line D H, then *from* C D′ into D′ F; and thus each concave surface aids in diverging the rays.

442. *Conjugate foci.*—In Fig. 163, where R is the radiant, and F its corresponding focus, the two points are called *conjugate foci.* If R is above the axis C C′, then F is below it, and the reverse, the two being in a straight line drawn through L, the center of the lens. If the rays, however, do not converge after passing through the lens, but *diverge,* as from some *apparent* radiant, still these points are called conjugate foci. When one of the conjugate foci is at an *infinite* distance, that is, when the rays are *parallel,* the other is called the *principal focus,* or focus of parallel rays.

443. *Images by the convex lens.*—The *convex lens* forms the same variety of images as the *concave mirror,* in respect to character, size, and position. When the object is *nearer* than the principal focus, the rays from each radiant still diverge, though from more distant points. Thus (Fig. 165), if M N is the object, the rays from the highest point M are bent towards the axis, so as to diverge less, as from the apparent radiant *m,* in the axis C M produced. In like manner, those from N diverge

Fig. 165.



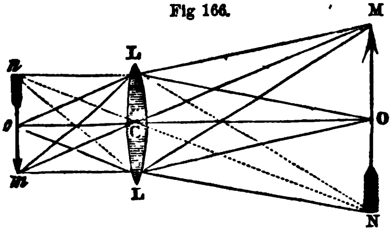
Explain the conjugate foci. If one is at an infinite distance, where is the other? What variety of images does the convex lens produce?

after refraction as from *n*. Thus, all the points of M N have their conjugate foci in the image *m n*. This is an *apparent* image, since the light, after passing through the lens and reaching the observer, *seems* to come from it, when in fact it does not. It is *erect*, because the axes of the extreme pencils C M, C N, do not cross between the object and the image. It is *magnified*, because it subtends the same angle M C N at a greater distance than the object.

When the object is *at* the principal focus, the rays of each pencil proceed in parallel lines, and hence seem to come from points *infinitely* distant.

444. When the object is *farther* from the lens than the principal focus, the rays become convergent to conjugate foci on the opposite side. Those from M (Fig. 166) meet in *m*, in the same axis, M C produced; those from O in *o*, and so of all other points. The image is *real*, being actually formed in the air or on a screen, and a person, standing beyond it, sees it by light which has really radiated from it. It is *inverted*, because the several axes M *m*, N *n*, &c., cross between it and the object. In size, it may be either larger or smaller than M N, according to the distance of the latter. For when M N approaches the lens,

Fig 166.



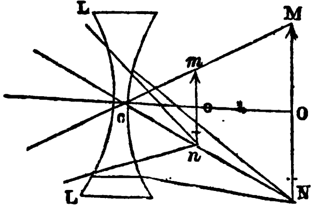
Describe the first case. What *kind* of image is it? Why? Why erect and enlarged? Where is the image when the object is at the principal focus? Why? When the object is further off than the principal focus? What kind of image is *this?* How are the diameter of object and image proportioned?

the image recedes from it, and grows greater; while, if M N is removed, the image approaches and becomes smaller. The diameters of the object and the image are always proportional to the distances, because they subtend the equal angles of the axes at C. The size of the lens has no effect on the size of the image, but only on its illumination.

445. *The convex lens a burning-glass.*—Heat is refracted as well as light, and therefore a convex lens, by converging the heat of the sun, becomes a burning-glass. The image of the sun, at the principal focus of a large convex lens, is so hot as to inflame combustibles at once.

446. *Images by the concave lens.*—Let M N (Fig. 167) be the object. The rays from the point N, after passing the lens, diverge more than before, as if from *n* in the same axis, C N, and so of other points. Hence *m n* is the image, *apparent*, *erect*, and *smaller* than the object, resembling in all particulars the image formed by the convex mirror.

Fig. 167.



447. *Spherical aberration.*—If lenses have a spherical curvature, the rays which pass through near the edge must, according to the law of refraction, be bent *too much*, to meet at the same focus with those near the center. Therefore, all the rays from any one point of the object do not unite in one point of the image, and hence arises more or less of indistinctness, according to the degree of curvature of the lens. This want of coincidence of rays is called *spherical aberration*. It cannot be

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Which kind of lens is a burning-glass? Show why. Describe the image formed by a concave lens. Describe what is meant by *spherical aberration*.

39

entirely prevented except by grinding the lens in a different form, so as to diminish the curvature of the outer parts.

448. *Atmospheric refraction.*—The atmosphere has an outer surface which is nearly spherical, and it increases in density from the top down to the earth. This spherical covering of the earth acts on light as a convex lens, bending the rays, which come from the heavenly bodies, gradually towards the perpendiculars or radii of the sphere. The effect is to elevate apparently all the heavenly bodies above their true places. Those near the horizon are elevated most, while a body in the zenith is seen in its true place. The refraction at the horizon raises the sun by a quantity about equal to its own breadth, thus bringing it into sight before it rises, and keeping it in view after it sets.

449. *Mirage.*—This phenomenon, called also *looming*, consists of the formation of one or more images of a distant object, caused by horizontal strata of air of very different density; particularly when the lowest stratum is, by the heat of the surface on which it lies, rendered more rare than the strata above. The surface of the rare stratum, in this case, produces *total reflection*, so that villages, groves, &c., may be seen both erect and inverted, and appear as if surrounded by water. The mirage is most likely to occur on hot deserts and prairies.

What rays are bent *too* much to meet others from the same point? What kind of lens is the atmosphere? How does it affect the light of the heavenly bodies? Which way are they displaced? Effect on the time of rising and setting? Describe *mirage*, and explain the cause.

CHAPTER IV.

DECOMPOSITION OF LIGHT.—THE RAINBOW.—COLOR BY REFLECTION, ETC.

450. *The prismatic spectrum.*—The refraction of a beam of light, in entering another medium, is not the only change which it undergoes. It is also *decomposed*, or separated into colors. A glass prism is generally employed for exhibiting decomposition. For convenience in experiment, it is mounted on a jointed stand, so that it can be placed in any desired position across the sunbeam admitted into a dark room. The beam, as already shown (Art. 437), is turned away from the refracting edge. But it is found that some rays are bent more than others out of their original direction; hence, the circular beam does not retain its form after passing the prism, but falls on the screen in a long band instead of a circle. This band consists of a series of colors, and is called the *prismatic spectrum*, or more properly, when the light comes from the sun, the *solar spectrum*. Let F (Fig. 168) be the opening through which the light enters, and Y the luminous circle, where it falls. As soon as the prism A B C is interposed, with its refracting edge C placed lowest, the beam is bent upward, both in entering the glass and in leaving it, and the spectrum is projected on the screen. The colors are arranged as in the figure, the *red* being the *least*, and the *violet* the *most* refracted. Though *seven* colors are described as composing the spectrum, namely, *red*, *orange*, *yellow*, *green*,

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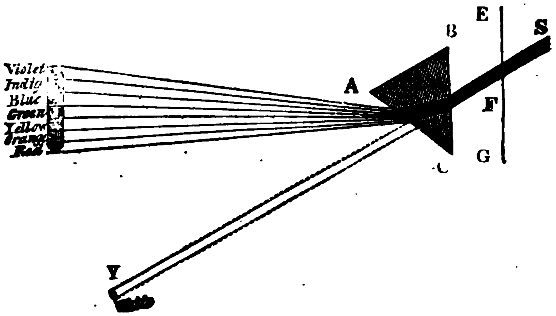
What other change does light suffer in going into a new medium? What
40 instrument is used for this? 41 Are all rays bent alike in passing through a
prism? What *form* does a circular beam take after passing through? De-
42 scribe the arrangement. State the *order* of colors.

blue, *indigo*, and *violet*, yet these are not distinctly separated from each other, but blended together in such a manner, that the whole might with as good reason be divided into a greater or a less number. If the refracting edge of the prism were to be placed highest, the beam would be bent *downward*, and the violet would be the lowest color, and the whole spectrum reversed; showing that red is always the least refrangible color,

Fig. 168.



and violet the most, and that the order from one to the other is always the same. But the prism reveals other rays, as coming from the sun, which do not affect the eye; for example, the rays of heat are *less* refracted than any colored rays, since the thermometer is most raised when placed a little outside of the red. And if suitable tests are applied, it is found that the chemical rays are more refrangible than any color, lying beyond the violet.

451. The prism decomposes, in the same manner as now de-

Which is the most refrangible? Which the least? Where is the *heat* collected? Where the *chemical* rays? Speak of light from other sources.

scribed, the light from any other source, and shows us, moreover, that every luminous body has its own peculiar kind of light; or, at least, that the colors exist in different proportions in them all; each star forms its own peculiar spectrum, different from that of the sun, and of every other star.

452. *Recomposition of light.*—As white light can be separated into its elementary colors, so these colors may be recombined, and form white light. One method is to place directly beyond the prism a second prism of the same angle, with its refracting edge turned the opposite way. Then, the separation caused by the first prism is neutralized by the second, and a white spot is produced, as though no prism had been interposed. Or, by revolving a prism swiftly, the spectrum may be made to pass back and forth over the same space so rapidly, as to produce on the eye the effect of a white, instead of a colored band.

453. *Complementary colors.*—Any two colors which, when mingled together, produce white light, are called *complementary* colors. Thus, if *green*, *blue*, and *yellow* were mingled, they would compose a green nearly like the green of the spectrum; then, if the remaining colors, *red*, *orange*, *indigo*, and *violet*, were blended in another color, it would be a species of purple. Now, these two compound colors, green and purple, if united would compose white, because the whole of each component of white is in it. Hence, these particular shades of green and purple are complementary colors. In the same manner, every possible shade of color, whether simple or compound, has its complementary color; and if the two were mingled, the result would be white light.

How can the colors be recombined? Second way? What is meant by
43 **complementary colors? Illustrate by an example.**

454. *Dispersive power of a medium.*—All substances are not alike in their *degree* of separation of colors. If a prism of flint glass, and one of crown glass, are made of such angle as to *refract* a beam equally, the flint glass will *separate* the colors most. Hence, flint glass is said to have the greatest *dispersive power.* The discovery of unequal dispersive power in various media has proved of great importance, because it has led to the removal of a serious difficulty in the formation of perfect images by lenses.

455. *Chromatic aberration of lenses.*—This is a deviation of the rays of different colors from one focus. The violet rays, being most refrangible, will be most bent in passing through a lens, and will therefore meet in a nearer focus than any other colors; while the red, the least refrangible, will meet in the most distant focus. Thus, of all the light which comes from one point of an object, only the rays of a particular color will be collected in the corresponding point in the image, and the others will be diffused around it, overlapping the rays from other points, and causing indistinctness.

456. *Achromatic lens.*—The difficulty above mentioned is nearly remedied by making the lens of two parts, namely a convex lens of one kind of glass, and a concave lens of another kind having a greater dispersive power. The convex lens converges the rays to an image, and separates the colors to a certain extent. The concave lens (of less curvature) diminishes this convergency, and removes the image farther off, but, having greater dispersive power, it reunites the colors, and renders the image distinct. The convex lens is usually made of crown glass,

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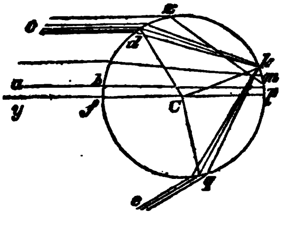
Do all substances separate the colors in the same *degree?* What is meant by *dispersive* power? Compare crown and flint glass. Show why a lens brings different colors to different foci. What is this deviation called? Why injurious? How can it be remedied? Describe the *achromatic* lens.

and the concave of flint glass; the two are placed in contact, and appear as one lens, in the form of a meniscus.

457. *The rainbow.*—This phenomenon, when fully formed, consists of two colored circular arches, projected on the falling rain, when the sun is shining on it from the opposite part of the heavens. They are called the *inner*, or *primary* bow, and the *outer*, or *secondary* bow. Each contains all the colors of the spectrum, arranged in contrary order: in the primary, red is outermost; in the secondary, violet is outermost. The primary bow is narrower and brighter than the secondary. The center of the bows is at a point of the sky exactly opposite to the sun; and, of course, a line drawn from the sun through the spectator's eye passes through the center; this line is called the *axis* of the bows. The colors of the rainbow are the effect of a decomposition, produced by the drops of rain, as the rays enter and leave them. The light which forms the primary, or inner bow, is *once* reflected in the interior of the drop; that which forms the secondary, or outer bow, is *twice* reflected within the drop.

Fig. 169.



458. *Course of rays in the primary bow.*—Let *f z p* (Fig. 169) be a section of a drop of rain; *y f*, *a b*, &c., rays from the sun entering it. That which passes through the center, *y f p*, marks what is called the axis of the drop, and suffers no refraction, and, if reflected at *p*, returns in the same line. Other rays, *a b*, *c d*, &c., are all more

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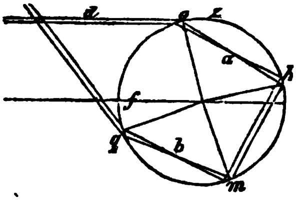
4/ What does the rainbow consist of? Describe the two bows. How many times is the light reflected in the inner? In the outer? Why are they colored? Compare the order of colors. Trace the rays in forming the primary bow.

46

or less refracted toward the axis; and when they reach the back side, some of them are reflected, and emerge on the front side. Now, it is shown by calculation, that it is only a narrow pencil, *c d*, entering at about 60° from the axis, whose rays of any one color, on emerging, continue together in an intense beam. It is this pencil which is concerned in forming the primary bow; all the other rays entering on the whole front of the drop, after being once reflected, scatter in various directions, and so produce only faint illumination of the cloud. This pencil, *c d*, being reflected at *k*, and emerging at *q*, is refracted *from* the perpendicular, C *q* produced; of course, the *violet* is bent *most* toward the axis *y p*, and the *red least.* And the rays of each color, being parallel among themselves, may proceed many rods, and even miles, and still appear very bright. The violet pencil is found by calculation to make with the axis of the bow the angle of 40° 17′, and the red, an angle of 42° 2′. Hence, these colors are seen at those distances respectively from the center of the bow.

459. *Course of rays in the secondary bow.*—Let *f z m* (Fig. 170) be a section of a drop, as before. There is a pencil *d e*, entering about 71° from the axis, which is found by calculation to describe the course *e h*, *h m*, *m q*, within the drop, and then emerge in rays which are parallel (so far as any one color is concerned), and cross the incident pencil in front of the drop.

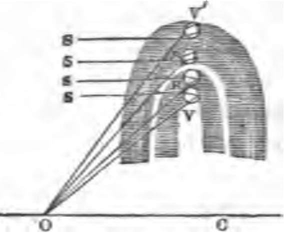
Fig. 170.



What pencil is concerned? What becomes of the others? How can this pencil be bright at a great distance? What angle does the violet make with the axis? The red? What pencil is employed in forming the secondary bow?

As the violet is refracted most from the radius at *q* produced, it will make a larger angle with *d e* than other colors, and the red will make the least. It is calculated that the angle for violet is 54° 9′, red, 50° 59′, and intermediate angles for the other colors. As a pencil, entering the *upper* part of the drop, *ascends* after emerging, let a pencil be selected 71° *below* the axis, and this will *descend*, and may enter the eye of an observer, who will then, though at a great distance, perceive a distinct color. All other rays emerging after two reflections, except those now described, diverge from each other, and produce but little illumination.

Fig. 171.



460. *Circular form of the bows.*—Let S O C (Fig. 171) be the axis of the bows, passing through the observer's eye at O, and S V, S R, &c., rays from the sun falling on the drops. Let V O C=40° 17′; R O C=42° 2′; R′ O C=50° 59′; and V′ O C=54° 9′. Then V will be the violet, and R, the red, of the primary bow; and R′, the red, and V′, the violet, of the secondary bow. Now, if the whole system of lines be revolved about S C as an axis, these rays will not change their angles with each other, nor with the surface of the drops; and therefore the same colors will appear around the entire circumferences, for the same reason as at the highest points.

Trace it through. Which color makes the largest angle with the axis? What angle for violet? For red? Does the light which reaches the observer enter on the inner or outer quadrant of the drop? What becomes of other rays? Explain by figure why the bows are circular. Show also the reason for the inversion of the colors.

461. The order of colors in the two bows is inverted, because the rays of the primary bow, emerging on the side of the drop *nearest* to the axis of the bow, are refracted *from* it, while those of the secondary, emerging on the *remote* side, are refracted *toward* the axis. Thus, in Fig. 171, if V O is violet, then other colors from that drop lie below it, and do not reach the eye at O; and in order to bring other colors to O, drops must be selected higher up, that is, farther from the axis. Hence, violet is the innermost color. So, if V′, after two reflections, is violet, then other colors, being refracted downward in a less degree, lie *above* O; and drops need to be taken lower down in order to bring other colors to O. Therefore, violet is the outermost color of the secondary bow. The space within the primary bow is rendered somewhat luminous by scattered rays *once* reflected; and that without the secondary bow, luminous in a less degree by rays *twice* reflected; while that between the two bows is not illuminated by either, and is perceptibly darker.

462. When the sun is on the horizon, the center of the bow will be on the horizon also, and just half of each circle will be projected on the sky. But if the sun is elevated, the arcs will be diminished, since the center will be depressed as many degrees below the horizon as the sun is elevated above it. If, however, rain is falling quite near, especially when the observer is on a mountain, much more than semicircles, and possibly even whole circles may be seen, the lower parts being projected on the land between the observer and the horizon.

463. *The common halo.*—There are many varieties of halo

Give the order in each bow. What illuminates the cloud within the primary bow? Where is the cloud darkest? State the size of the bow when the sun is on the horizon. What is the effect of the sun being elevated? In what circumstances can a whole circle be seen?

sometimes formed about the sun; but one kind is of very frequent occurrence, seen both around the sun and the moon, and known as the *common halo.* Its distance from the luminary is about 22°; it is usually white, with a red inner edge; on the outside, it shades off gradually to the general illumination of the sky, while the inner border is more abrupt, and the space within darker than that without. It is formed by the refraction of rays from the sun or moon, by crystals of ice which float in the air, and whose refracting angle is 60°. The inner edge is red, since that color is the least refrangible, and the other colors are not clearly developed, because different ones more or less overlap each other, owing to the different positions of the crystals through which the light comes. Other and more complex forms of halo, rarely seen except in high latitudes, are formed by crystals of other angles than 60°.

464. *Color by reflection.*—The different refrangibility of the rays does not furnish the only means of decomposing light; but in several other ways it is found that the solar beam consists of the seven colors. The most familiar case occurs in the *natural colors of bodies.* The same white light falls on different flowers, yet one is red, another yellow, and so on; and not only so, but of the red flowers there are innumerable shades and tints, and the same is true of each prismatic color. It is clear, that if a body when placed in white light appears red, it is because it *reflects* red rays to our eyes, while the other colors are absorbed, or in some way lost. So, a leaf is green, because it reflects only the green rays. Again, the several shades of each color arise from the reflection of more or less of some other rays, along with the one which is principally reflected. A sub-

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Describe the common *halo.* How is it formed? Explain the *colors* of natural objects. How are there so many varieties of each color?

stance which reflects *all* colors in equal proportion is white; and one which reflects none is black.

465. *Inflection of light.*—When a pencil of light from a single point, or from a very narrow line, flows past the edge of a body, casting a shadow on a screen, the edges of the shadow are fringed with delicate bands, each containing the colors of the spectrum. This effect is called *inflection.* The reason why we do not always see the edges of shadows thus bordered, is that the light, usually coming from *many* luminous points at once, obliterates the effect by the overlapping of the several pencils. If a person in a room looks at a distant window, and holds any straight edge, as of a book-cover, close to the eye, and moves it along, so as nearly to coincide with a bar of the window-sash, he can see colors along the sides of the bar, the *blue* part of the spectrum next to the cover, the *red* part on the other side of the bar.

466. Interesting experiments on inflection are performed by permitting the sunlight from the focus of a lens to pass through minute apertures, and then fall into the eye through a magnifier. The colored images of a distant lamp, seen through the network of a bird's feather, are a beautiful example of inflection.

467. *Striated surfaces.*—Very brilliant colors are produced when the sunlight is reflected from a surface which is grooved with *fine parallel lines.* Such a surface is said to be *striated.* The grooves need to be less than a 2,000th of an inch apart. The colors of the shell known as *mother-of-pearl* are of this kind; as also those of many other kinds of shell, whose tints

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Describe *inflection* of light. Why are not shadows *always* bordered by fringes of color? Describe experiment on window-bars. Bird's feather. What is a striated surface? What its effect? Examples.

are changeable. The grooves of shells are caused by the edges of laminæ which crop out on the surface. The changeable hues in the plumage of some birds, and in the wings of some insects, are owing to a striated structure of their surfaces. But the metals can be made to furnish the most brilliant spectra, by stamping them with steel dies, which have first been ruled by a diamond with exceedingly fine lines. Gilt buttons, and other articles for dress, are sometimes prepared in this manner, and are called *iris ornaments*. The colors vary both by a change of distance between the lines, and by the inclination of the surface to the light.

468. *Thin laminæ.*—Any transparent substance, when reduced in thickness to a few millionths of an inch, reflects brilliant colors, which vary with every change of thickness. Examples are seen in the thin laminæ of air occupying cracks in glass and ice; in thin films of oil on water; but most remarkably in thin soap-bubbles. To exhibit the colors in regular systems, Sir Isaac Newton's method is best; that is, to place a very flat convex lens on a concave of slightly greater curvature, so that there shall be an exceedingly thin space between them all around the central point of contact, to the edges. In this thin film of air, the colors are seen in concentric rings, repeated several times, till the outer ones are almost too faint to be seen. These are known as *Newton's rings*. Having measured the diameter of the rings, and knowing the curvature of the lens, Newton was able to calculate the thickness of air at each one of the colors. He found that when air is reduced to less than *half a millionth* of an inch in thickness, it reflects no light; that

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How are the grooves formed in shells? What are *iris* ornaments? Examples of *thin* laminæ producing color. Describe Newton's mode of experimenting. At what thickness of air does it cease to reflect?

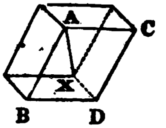
is, the space near the center of the rings becomes black, when reduced to that thickness; and when the thickness is greater than *seventy-two one-millionths*, the colors are all blended in white. Newton's rings are especially beautiful and interesting, when light of only a single color falls on the lenses. The luminous rings are then all of that color, separated by rings which are perfectly black, and, instead of stopping with the number of *eight* or *ten*, they can be counted by *hundreds*, becoming more and more narrow and delicate as they are removed from the center of contact, till a microscope is needed to trace them.

CHAPTER V.

DOUBLE REFRACTION.—POLARIZATION.—WAVE THEORY.

469. *Double refraction.*—There are many transparent substances, particularly those of a crystalline structure, which, instead of refracting a beam of light in the ordinary mode, *divide it into two beams.* This effect is called *double refraction*, and substances which produce it, *doubly refracting substances.* The most common example is a carbonate of lime, called *Iceland spar.* Its form (Fig. 172) is a parallelopiped, having six rhomboidal faces. As a thick specimen of it lies on a line of writing, the line appears *doubled*, one image usually somewhat overlying the other.

Fig. 172.

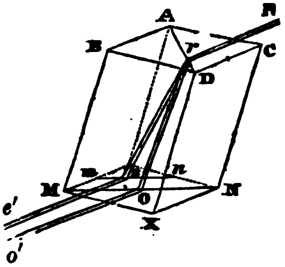


470. *Ordinary and extraordinary rays.*—Instead of observ-

At what thickness does it reflect all colors and appear white? State the effect of *one* color. Define *double* refraction. Example.

ing writing or other objects to be doubled, as we look through the crystal, a beam of light, R *r* (Fig. 173), may be allowed to fall upon it; then, as it enters, it divides into *r* O and *r* E, and after emerging, proceeds as two separate beams, O *o′* and E *e′*, parallel to each other, and to the incident beam, R *r*. One of these, *r* O *o*, conforms to the usual laws of refraction, remaining in the plane of incidence, and preserving a constant ratio of the sines of incidence and refraction, at all inclinations; it is therefore called the *ordinary* ray. The other, *r* E *e′*, departs from the plane of incidence, in most cases, and does not maintain a constant ratio of sines; for these reasons, it is called the *extraordinary* ray.

Fig. 173.



471. There is one direction, however, in which light may pass through the crystal, without being doubly refracted. That direction is marked by the line A X (Fig. 172), joining the obtuse angles. At whatever point the ray enters, if it is bent by refraction into a line parallel to A X, it is *singly* refracted, as by any ordinary medium. Some crystals have two such directions through them, and are called crystals of two axes; and a few have more than two. By applying pressure to pieces of glass, also by heating and suddenly cooling them, they may be so changed in their structure as to become *double refracters*.

472. *Polarization.*—This name is given to a change which may be produced in light, such that it has different properties

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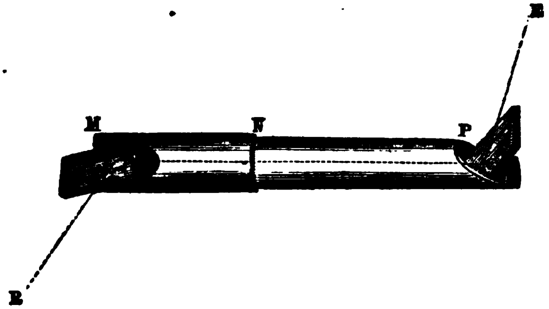
Names given to the rays? Modes of showing them? Why is one called the *extraordinary* ray? In what direction is the ray *not* divided? How can substances acquire the property artificially? What does *polarization* mean?

on different sides. *Common light*—as, for instance, a direct sunbeam—has the same relations to space on all sides. If it falls on a piece of glass at a given angle, it will suffer reflection equally well in every plane, as the glass is turned round; and the same is true of refraction, or any change whatever. But if a beam should be so changed that it might be reflected *upward*, but could not be reflected to the *right*, it would be called, not *common*, but *polarized* light.

473. *Polarization by reflection.*—A frequent mode of polarizing light, is *to reflect it from glass at an angle of* 57°. Fig. 174 represents the essential parts of a *polariscope*; that is, an instrument for polarizing and analyzing light. The tubes M N and N P fit together, so that one may be easily turned around in the other. The plates A and C are pieces of dark glass, attached to the tubes at such an angle that the ray, R A, will, after reflection at an angle of 57°, traverse the axis of the tubes,

Fig. 174.



Is common light polarized? What is the proof? Describe the first mode of polarizing. What is a *polariscope?* Describe one kind. At what angle of incidence does glass polarize?

and fall upon C at the angle of 57° also. A is called the *polarizing plate*, and C the *analyzing* plate; for the first *polarizes* the ray, and the second *proves* it to be polarized. The ray from A to C is polarized; for if the tube, N P, is turned round in M N, the beam reflected from C will sometimes be bright, and sometimes very faint, although A C falls upon C at the same angle, during the whole revolution. In the position in the figure, the spot E is the most faint; and if the analyzing plate is turned over so as to reflect *downward*, the spot on which the ray falls is also faint. But if the tube is turned so as to reflect forward or backward, in the same plane as the first reflection, B A C, the light reflected from C will be bright; and, during each quadrant of revolution, the change will be gradually made from the brightest beam to the faintest, or the reverse.

474. All substances polarize by reflection in some degree; some at one angle, some at another. The metals polarize only very slightly; hence the reason why the polariscope will not succeed well, if pieces of *looking-glass* are used in the place of A and C; for in a looking-glass, metal, and not glass, performs the principal reflection.

475. *Polarization by double refraction.*—There are several other ways of polarizing light, beside the one above described; but there is none so perfect, as to transmit the beam through a doubly-refracting crystal; for such a crystal polarizes both the ordinary and the extraordinary ray, and renders the polarization more complete than can be done in any other way. If a double

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Proof that the ray A C is polarized? Describe the changes which occur as the tube revolves. Do other substances polarize by reflection? What is said of the metals? Will plates of looking-glass answer for these experiments? Why? What is the best way of polarizing? State the effect of placing a double refracter for a polarizer.

refracter takes the place of A (Fig. 174), then two beams will generally be seen reflected from the analyzer, C; but in the position represented in the figure, only one will be seen; and when the tube begins to revolve, that one grows faint, and the other appears and grows bright, till, after 90° of revolution, the latter is seen alone, the former bright one having disappeared. This change occurs in each of the quadrants.

476. *Color by polarized light.*—Many interesting and beautiful phenomena of *color* are presented in the experiments performed with polarized light. Thus, if a thin film of doubly-refracting mica is interposed in the tube (Fig. 174), so that the polarized ray, A C, shall pass through it, the beam C E, in some positions of the analyzer, will be brilliantly colored; and when the analyzer revolves, this color will pass into its complementary color at the end of 90°, and back to the same again at the end of 180°. The kind of color produced depends on the thickness of the film of mica interposed, so that, by varying the thickness, every tint of the spectrum can be seen.

477. *Systems* of colored rings, both of simple and complex forms, are also exhibited by various kinds of crystals placed in the polarized beam, revealing interesting facts respecting their internal structure.

478. *The wave theory.*—The principles of this theory, which is now generally received, are the following:

1. *An exceedingly rare and elastic ether fills all space*, both about and within other bodies, and its elasticity is least within bodies of greatest refractive power.

2. *Bodies called luminous have the power of exciting vibrations*

Describe the changes. How are experiments on color performed? What change occurs as the analyzing plate revolves? What do the colors depend on? In the wave theory, what kind of ether is assumed to exist? State the *second* principle.

in this ether. How they do this is not known. Sounding bodies excite vibrations in air, by vibrating at the same rate themselves; but that luminous bodies produce light in the same manner is only probable, not certain.

3. *These vibrations travel* in all directions, *at the rate of* 192,500 miles per second.

4. *The vibrations of the ethereal atoms are transverse,* or *across* the line of the ray, and that, too, *in all directions,* in quick succession. It has already been noticed that *water* vibrates transversely, in *one* direction, and that air, in conveying *sound,* vibrates longitudinally. It is a little more difficult to conceive correctly of the vibrations in light. It may be illustrated thus: Suppose a star exactly overhead; the ray which comes down into our eye consists of tremors of the particles of the ether, north and south, northeast and southwest, east and west, and in all *other horizontal* directions. And the number of vibrations in a second is so exceedingly great, that we commit but a slight error in saying that an atom vibrates in these millions of directions *all at once.*

5. *Colors are caused by different rates of vibration,* just as pitch in sound depends on the rate of the aerial vibrations. *Violet* is caused by the *most rapid* vibrations, corresponding to a high tone in music; *red,* by the *slowest* rate, corresponding to a low tone.

479. The most wonderful fact pertaining to the nature of light is the inconceivable rapidity with which the vibrations are made. For extreme *red,* it is 458 trillions (458,000,000,000,000)

Is it known *how* luminous bodies produce the vibrations? At what *rate* do the waves travel? What is the *mode* of vibration? Illustrate by light from a star. What constitutes *color,* according to this theory? What *color* in light corresponds to a high pitch in sound? How many vibrations per second in a red ray.

of vibrations in a second of time; for extreme *violet*, 727 trillions per second; and the mean rate is 541 trillions per second. In order, therefore, to transmit light through space, every atom of the ether must, *during each second*, perform three thousand times as many vibrations as there have been seconds from the creation of man to the present time.

CHAPTER VI.

OPTICAL INSTRUMENTS.—VISION.

480. *The microscope.*—This, as the name imports, is an instrument for *viewing minute objects.* The simplest kind is a *convex lens.* It has been shown (Art. 443) that when an object is nearer a convex lens than its principal focus, the rays are made less divergent, and form an apparent image on the same side of the lens. This image fills the same angle at the lens as the object does. But, as the eye may be close to the lens, the image may subtend an angle many times greater than it would do when viewed by the unaided eye; and it appears magnified in the same ratio. If the ordinary limit of distinct vision be called *five* inches, then a microscope, whose focal length is one-fourth of an inch, would magnify 20 times in diameter, because the object, being twenty times nearer, would fill an angle about 20 times greater.

481. *The compound microscope.*—This instrument consists of an *object-glass* and an *eye-glass.* The object-glass first forms a

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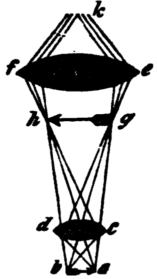
What is the average number? Define the *microscope.* What is the simplest kind? How does it enable us to see an object larger? How is the magnifying power estimated? What does the compound microscope consist of?

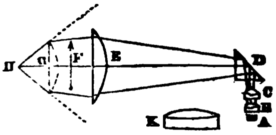
real and enlarged image of the minute object, and the eye-glass is used as a single microscope for viewing this image. The object, *a b* (Fig. 175), being placed a little beyond the principal focus of the object-glass, *cd*, forms a real and inverted image, *g h* (Art. 444); and then the eye-glass, *e f*, is so situated, that *g h* is slightly nearer than its principal focus; then the eye, at *k*, views this image by the aid of *e f*, as a single microscope. The object appears magnified, both because the image itself is larger than the object, and again because it is viewed so near, by aid of the eye-glass. If the image, *g h*, is in diameter ten times *a b*, and is viewed twenty times nearer than in ordinary vision, the magnifying power of the instrument is 200 in diameter, or 200^2 (= 40,000) in area.

Fig. 175.



482. When very great magnifying power is attempted, indistinctness is produced by the spherical and chromatic aberrations. The greatest modern improvements in the compound microscope consist in the removal, to a great extent, of these difficulties. Fig. 176 represents the arrangement of parts in some of the best instruments. A is the object; B, C, constitute the object-glass, consisting of two plano-convex lenses, each composed of a plano-concave of flint glass, and a double convex of crown glass (in the form shown

Fig. 176.



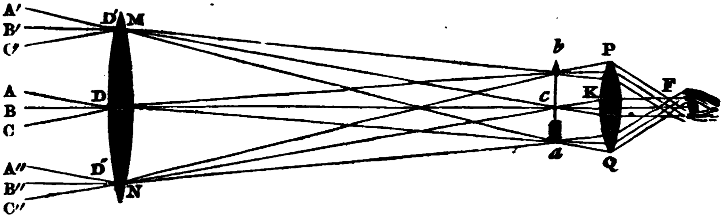
What is the office of the object-glass? Of the eye-glass? Illustrate by the figure. Show how the power is estimated by an example. What modern improvements have been made? Describe by the figure.

at K), for destroying the chromatic aberration. D is a right-angled prism, for turning the rays from a vertical to a horizontal direction by total reflection. E and F form the eye-glass, being in two parts, in order to diminish spherical aberration. The eye, at H, sees the object filling the angle between the dotted lines.

483. *The telescope.*—The telescope is an instrument for *viewing distant objects.* An image is first formed by a convex lens, or a concave mirror, and then a single microscope is employed for viewing the image, as though it were a small body. If the image is formed by a lens, the instrument is called a *refracting telescope;* but if by a mirror, a *reflecting telescope.*

484. *The astronomical telescope.*—This is the most simple of the refracting telescopes, consisting of a lens (called the object-glass), to form an image of the heavenly body, and a single microscope (the eye-glass), for magnifying the image. The image is at the principal focus of the object-glass, and the eye-glass is placed at its own focal distance from the image, in order that the rays of each pencil may emerge parallel; there-

Fig. 177.



What is the purpose of the telescope? What is accomplished by the object-glass? By the eye-glass? What two classes of telescopes? Describe the *astronomical telescope.* Where is the *image?* How far from it is the eye-glass placed?

fore, the two lenses are separated from each other by the sum of their focal distances. In Fig. 177, M N is the object-glass, P Q the eye-glass. A real image, *a b*, of the heavenly body is formed in the manner described (Art. 444). Though the rays of each pencil are parallel after passing through P Q, yet the pencils themselves converge toward the axis; and F, where they meet, is the place for the eye.

485. *The powers of the telescope.*—The *magnifying power* equals the ratio of the focal distance of the object-glass to that of the eye-glass. For, if a person should place his eye at the object-glass M N, the image *a b* would fill the angle *a* D *b*, which equals A D C, the angle filled by the object; therefore, it would appear just as large as the object. But when he is at the eye-glass P Q, it fills an angle about as much larger as it is nearer. Hence, it appears magnified in the ratio of D *c* to K *c*. It is therefore possible to magnify to any degree that is desired, since the ratio of focal distances may be made as great as we please. But it is of no use to *magnify*, if the image is not both *luminous* and *distinct*. To secure a high *illuminating power*, in viewing faint objects, the object-glass should be large, so that as many rays as possible may come from the object to form the image. And, that the image may be *distinct*, in other words, that the instrument may have a good *defining power*, it is necessary to remove as far as possible the spherical and chromatic aberrations, and all inequalities in the structure of the glass. From these last particulars arise the chief difficulties in

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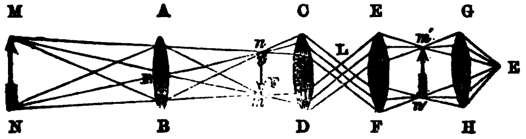
Describe by the figure. How are the *pencils* of parallel rays related to each other, after passing through the eye-glass? How is the *magnifying* power estimated? Show that this is true. Is the magnifying power made as great as possible? Why? What other powers are to be considered? How is great *illuminating* power obtained? What must be done to secure good *defining* power?

the way of making a good telescope. And these difficulties increase at a rapid rate, as the object-glass is enlarged. To diminish the *spherical aberration*, the object-glass is ground so as to be slightly less curved toward the edges (Art 447), and the eye-glass is made of two plano-convex lenses. To prevent, as far as possible, the *chromatic aberration*, the object-glass consists of two parts, a convex lens of crown glass, and a concave of flint glass, as described in Art. 456. The difficulty of removing all inequalities of density from large lenses is so great, that no object-glass of excellent quality has yet been prepared, whose diameter is more than fifteen or eighteen inches.

486. *Terrestrial telescope.*—In order to secure simplicity, and thus the highest excellence, in the astronomical telescope, the image is allowed to be *inverted*, a circumstance of no importance in viewing the heavenly bodies. For terrestrial objects it is necessary to add other lenses, in order to bring the final image erect. A telescope having such a construction is called a *terrestrial telescope*, or a *spy-glass*. In Fig. 178, M N is the object; A B, the object-glass; *m n*, the inverted image, slightly beyond the principal focus; C D, the first eye-glass, which renders the rays of each pencil parallel, but converges the pen-

Fig. 178.

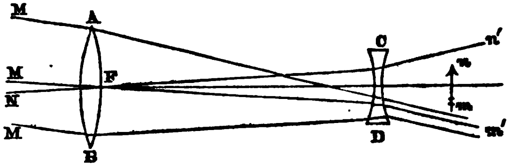


What are the great difficulties in the way of making a good telescope? How remedied? How large an object-glass of first quality has been made? In what position are the objects seen? What is done to fit the telescope for terrestrial use? Describe the instrument.

cils themselves to L. Instead of placing the eye at L, as in the astronomical telescope, a second eye-glass, E F, is placed so as to receive them all after they have crossed, and converge them to points in a second image, *m′ n′*. This image is *erect*, because of the crossing of the pencils at L. The third eye-glass, G H, is the microscope with which *m′ n′* is magnified. Such instruments are usually of portable size; and to render them still more convenient for transportation, they are often made of separate tubes, which slide together in a very compact form.

487. *Galilean telescope.*—This was the first form of telescope, having been invented, as the name implies, by Galileo. It differs from the common astronomical telescope, in having a *concave* lens for an eye-glass. Fig. 179 explains its construction.

Fig. 179.



The convex object-glass converges the rays, M A, M F, M B, which come from the top of the object, toward *m*, the bottom of the image; and the rays from the bottom of the object (parallel to N F), toward *n*, the top of the image. But before the pencils reach these focal points, they are intercepted by the concave lens, C D, which renders the converging rays of each pencil parallel, and thus brings them to the eye. The object appears erect, because the pencil from the highest point still

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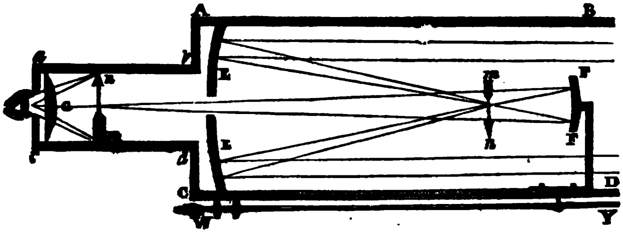
How is the spy-glass made portable? What was the earliest form of telescope? By whom invented? Describe it.

appears to come from the top of the virtual image, and the lowest pencil from the bottom. But, on account of the increased divergency of the several pencils, only the central ones can enter the eye; and, for this reason, the field of view is quite limited. It has little value except as a *finder*, or as an *opera-glass*, to be held in the hand; for such uses it is convenient, on account of its compact form.

Fig. 180.



488. *Gregorian telescope.*—This is the most frequent form of reflecting telescope, so named from its inventor, Dr. Gregory, of Scotland. The light from a heavenly body, entering the open tube, B A D C (Fig. 180), is received on the large concave speculum, E E, which forms an inverted image, *m*-*n*, at the principal focus; the rays of each pencil, having crossed each other in the points of this image, fall on the small concave mirror, F F, which is distant from it a little more than its own focal length; hence, another image, *m n*, is formed beyond its center of concavity, inverted in relation to the first, and therefore erect in relation to the object. This second image is in the eye-piece, *a b c d*, the light having been let through an opening

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What great disadvantage has it? For what purpose now used? What is the most common form of *reflecting* telescope? By whom invented? Describe it. What is the position of the first image? Of the second?

the center of the large mirror. The eye-glass for viewing this image is at *a c*, in the end of the small tube. To prevent confusion in the figure, only four rays are drawn, and those from the *center* of the object. These, after being reflected by E E, are collected at the center of the first image, and after reflection again by F F, are converged to the center of the second image. Rays from the *top* of the object would enter the tube inclining downward, and be collected at *n*, the bottom of the first, and the top of the second image; while rays from the bottom of the object would meet at *m* in each image. The small mirror F F, and the hole through the large one, do not intercept the view of any part of the object, but only diminish a little the light of each point of the image.

489. *Herschelian telescope.*—Sir William Herschel modified the Gregorian telescope by dispensing with the small reflector F, and inclining the speculum E E, so as to form the image near the edge of the tube, at D, where the eye-glass is attached, for viewing the first image *m n*. While some inconvenience arises from the situation of the observer, with his back to the object, much light is saved, and there is greater simplicity of the instrument. The speculum of Herschel's telescope was about four feet in diameter, and weighed more than 2,000 pounds. Its focal length was about forty feet. The Earl of Rosse has more recently constructed an Herschelian telescope, having an aperture of *six* feet, and a focal length of *fifty* feet.

490. *The perspective glass.*—This instrument consists of a large convex lens and an inclined mirror, fitted up for viewing

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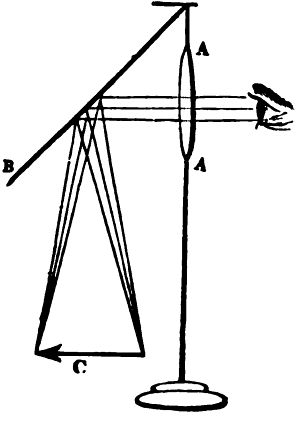
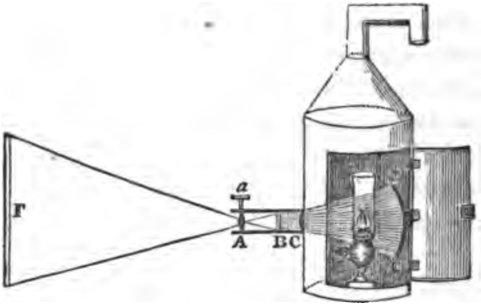
Does the small mirror hide any part of the object? How is this telescope changed to an Herschelian? What inconvenience attends the latter? State the size of Herschel's. Of Lord Rosse's. What does the *perspective glass* consist of?

Fig. 181.



pictures. The lens, A A (Fig. 181), is placed vertically in a frame or side of a box, and behind it the plane mirror B B, inclined at an angle of 45°. The perspective, C, lies horizontally below the mirror; and if the whole distance from it to the mirror, and thence to the lens, is less than the principal focal length of the lens, then the image will be an *apparent* one, situated behind the mirror, in an erect position. The picture appears *magnified*, and the view of surrounding objects being excluded, the *representation* seems like a *reality*.

Fig. 182.



491. *The magic lantern.*—This is an instrument for pro-

Describe. Why do pictures appear like realities? What is the purpose of the *magic lantern?*

jecting on a screen, *real* and *much enlarged* images of transparent paintings. It consists of a box (Fig. 182), containing a lamp, and having openings above and below, so arranged as to allow free ventilation, without permitting any light to escape. In front of the lamp is a convex lens, C, for concentrating the rays upon the transparency. A concave mirror, E E, behind the lamp, also helps to increase the light. B is the place of the painting on glass, and A is the lens, by which a distant and magnified image, F, is formed. It is necessary to illuminate the object B as much as possible, because the light radiating from it is to be spread over an image hundreds of times larger, and the light of it therefore as many times less. By an adjusting screw, *a*, the distance between A and B may be altered, so as to bring the image accurately on the screen. The magic lantern is employed for purposes of amusement, and also for illustrating some branches of science.

492. There are several modifications of the magic lantern, having specific names, according to the particular use to which it is applied. Thus, it is called *phantasmagoria*, when it is furnished with mechanism by which the exhibiter may alter its distance from the screen, and produce a corresponding change in the focal length of the lens. If the lantern recedes from the screen, and the image is kept distinct, it enlarges in size, and therefore seems to be approaching the spectators. The *polyrama* is a combination of two magic lanterns, for exhibiting what are called *dissolving views.* The two lanterns are placed so as to throw their images upon the same ground; but, while one lamp is shining with its full brightness, the other is made to

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Describe it. How is the light concentrated? What objects are employed? How is the picture made distinct? When is the instrument called *phantasmagoria?* When called *polyrama?* How does one image dissolve into another?

grow gradually dim, and thus the picture which it formed by degrees fades out, and disappears. The operator then can diminish the intensity of the bright light and increase that of the other, thus causing the two pictures to blend, while one slowly disappears, and the one before invisible comes to its full brightness.

493. *The solar microscope.*—This does not differ in principle from the magic lantern. But, for illumination, the *solar* or *electric* light is used, and images are formed, not of transparencies, but of minute natural objects. The lens, which forms the image, is fixed in the end of a tube, and at the other end is a mirror, which can be turned on a hinge, to incline at any angle with the axis of the tube. This apparatus is attached to a window-shutter, the mirror on the outside, and the tube within the room. By adjusting-screws the mirror is so inclined as to reflect the sunbeam along the tube, where it is concentrated by lenses upon the minute object, lying just back of the image-lens. In this way the light may be made so intense, that the images of minute objects will be plainly seen when magnified millions of times in area. The electric light is often employed instead of solar light, and the instrument can thus be used when the sun is not shining. When images are so exceedingly magnified, the spherical aberration becomes a serious difficulty; and hence, though such instruments are valuable, as a means of affording entertainment or instruction, they are far inferior to the compound microscope for the purposes of investigation and discovery.

494. *The camera obscura.*—This name, which signifies *dark chamber*, is applied to any arrangement for producing by

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Describe the solar microscope. What kind of objects is used? Are the images perfect? Why? Are such instruments valuable for investigation? For instruction? Give the meaning of *camera obscura*.

a convex lens, a distinct real image of objects on a screen for copying. The image in the camera obscura is usually smaller than the object, though its size may be varied to any extent. If a lens be fitted into an opening in a window-shutter, the images of external objects are beautifully formed on a screen at the proper focal distance, representing the objects in form, relation, and color, in a perfect picture. They are, however, inverted, both vertically and horizontally; so that, if copied, and placed erect, they are still inverted from right to left. This can be remedied, by allowing the images to fall on a translucent screen, and copying them on the opposite side. Or, the light from the objects may first fall on a mirror, inclined 45°, and the images pictured on a horizontal table. As the mirror changes the relation of right and left, the images will be correct in that particular, when viewed right side up. The instrument becomes portable when the lens is placed in the side of a box, and the images are formed on the opposite side upon ground glass, so as to be seen through upon the back.

495. *The photographic art.*—The portable form of the camera obscura has come to be of inestimable value in the new art of *photography*, or *delineating by light*. The first process in the art of rendering permanent the image formed by a lens was invented by *Daguerre*, who prepared a metallic plate with a surface of polished silver, rendered that surface sensitive to the action of light by the vapor of iodine, and then let the image of the camera fall upon it. Pictures produced in this manner are called *daguerreotypes*.

The *photograph* is a picture formed on chemically prepared

Describe the arrangement. If the images are copied and turned right side up, are they correct? How can the evil be prevented? What is *photography?* Describe the first invention. By whom made? What were the pictures called?

paper, by light passing through the transparent parts of a picture which is first taken on glass, in a manner similar to a daguerreotype. The light which is transmitted darkens the paper, according to the degree of its intensity, and the *lights* of the picture, therefore, occur where *no* light is transmitted through the glass. The picture on the glass is called *a negative;* and the same negative may be used an indefinite number of times in multiplying photographs.

496. *Images by an aperture only.*—Inverted pictures of external objects may be seen, faintly formed on the wall of a darkened room, when the light enters through a *mere opening* in the opposite wall. Thus, if an aperture, an inch or less in diameter, be made in the tight shutter of a room, and all light be excluded except that which can enter through this aperture, then the opposite wall, or a screen a few feet distant from the window, will be covered with inverted images of all the external objects in sight. These images have the same colors and forms as those of the camera obscura, but they are *not distinct.* The outline of every figure, instead of being sharply defined, appears blurred. And, if the *size* of the aperture is altered, it is noticed that, as it becomes *smaller*, the pictures have more distinct outlines, while, if it is enlarged, they are more confused. But the *form* of the opening has no influence whatever on the images; no change is produced by substituting for a *circular* aperture, one which is *square*, *triangular*, or of any other form.

497. The reason for these images is explained, when it is considered that every point of an external object sends through

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What is a *photograph?* Describe the process of making it. What is the *negative?* Describe the effect of an aperture in the wall of a dark room. Are the images distinct? Why? State the effect of altering the *size* of the aperture. Of altering the *form*. Explain why images are formed.

the opening a straight pencil of light, which falls on the opposite wall, and illuminates a small spot with the color of that point. Thus, if the hole is a small circle, a cone of rays from one point at the *top* of a tree passes through it, and falls in a small circle *low* on the wall; another from the *bottom* of the trunk strikes near the *top* of the wall in another circle; and, in a similar manner, a cone of light from every point of the tree forms a little circle in a corresponding part of the image. The picture is *inverted*, because the pencils all cross at the aperture. It is *indistinct*, because a *circle* takes the place of a *point*, and the circles which correspond to contiguous points must overlap each other, and mingle their light together. It is *more distinct*, though *less luminous*, when the opening is smaller, since the circles, being smaller, do not overlap so much, but approach towards the size of points, which they should be, in order for perfect distinctness. The *form* of the aperture is immaterial, since the arrangement of the spots continues the same, and the eye cannot discern whether the picture is composed of innumerable circles, or squares, or triangles, blending with each other. The irregular interstices between leaves of trees form so many circular images of the sun in the shadows of those trees on a smooth floor or pavement.

As soon as a convex lens is placed at the opening, the rays of the several cones or pyramids are converged to *points* on the wall, and then the parts of the picture become well defined like the objects themselves, as already described.

498. *The eye.*—The organ of vision is an optical instrument of wonderful perfection; and though, after long and care

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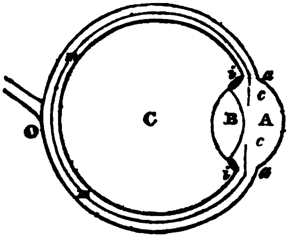
Why they are inverted. Why they become more distinct by diminishing the aperture. Why change of form does not alter them. Why does a convex lens make the pictures distinct? What instrument does the *eye* resemble?

Fig. 183.



ful study, there are in it some particulars not well understood, yet the general plan of its construction is simple. It may be considered as a *camera obscura*, since it consists of a darkened room, having aperture, lens, and screen, for the formation of images of external objects. The principal parts are represented in Fig. 183. The general form of the eye is a sphere, but the transparent front, *a a*, called the *cornea*, is ellipsoidal, and more prominent than the rest. Behind the cornea is the *aqueous humor*, A, a semi-liquid, like the white of an egg, in the back part of which is the *iris*, or *colored* partition, *c c*, having a round hole in the center of it, called the *pupil*. B is the *crystalline humor*, a double convex lens, of yielding solid material. The remainder of the eye, C, is occupied by the *vitreous humor*, very much resembling the aqueous. The crystalline humor has a little greater refractive power than the others; but none of them in this respect differ much from water. Back of the vitreous humor, and lining the whole sphere, beyond the edges of the crystalline at *i i*, is the *retina*, a delicate net-work of nerve, formed by the expansion of the *optic nerve*, O; which enters the back part of the eye, about 15° from the center, toward the nose. A second lining, *m m*, outside of the retina, called the *choroid coat*, has a jet-black surface next to the retina, which absorbs the rays as soon as they have excited the nerve, and prevents their reflection within the eye. The *sclerotic coat*, or white of the eye, is a firm case

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Describe the principal parts. What is the refractive power of the humors? What encloses the whole?

which encloses the whole, and unites with the edges of the cornea near the front.

499. As light comes to the eye, it is refracted principally at the surface of the cornea; for there is too little change of density to produce much convergency afterwards. The rays of all pencils which enter the pupil are converged accurately to corresponding points on the retina; and these are united in distinct images of external objects.

500. *Adaptations.*—The cornea is of ellipsoidal shape, and has the proportions which calculation shows to be requisite for preventing spherical aberration. For the same purpose, the crystalline is more dense in the central parts than toward the edges.

501. There is great advantage in placing the pupil *within* the eye instead of on the front; for now most of the convergency takes place before the rays reach the pupil, and, therefore, objects situated very obliquely are in sight. Without turning the eyes at all, a person can see all objects which lie within a range of 150°.

502. When an object approaches a lens the image recedes, and when the object removes to a distance, the image approaches the lens; hence, unless the curvature of the lens is changed, or the screen moved, there is indistinctness, since the converging rays in one case have not reached their focal points, and in the other have passed beyond them, and diverged. In like manner, since we can see distinctly at various distances, there must be in the eye the power of adapting itself to changes of distance. And we are conscious of making some muscu-

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Where does the refraction mostly take place? On what are the images formed? What is the form of the *cornea?* Why? Why is the pupil not at the front? How far around can we see without turning the eyes? How is the eye adjusted to different distances?

lar effort to alter the condition or form of the eye, whenever we look first to a near and then to a distant object, or the reverse.

503. The eyes of animals are adapted, in respect to their refractive power, to the medium which surrounds them. The human eye is exactly fitted for seeing in *air*, but would not answer that purpose in *water*, because its density is almost equal to that of the humors of the eye; hence, a pencil of rays, passing from water into the eye, would scarcely be converged at all.

504. The pupil of the eye can enlarge or contract, according as more or less light is needed. This change takes place involuntarily, and may be seen in a glass, whenever the degree of light is suddenly changed. It is partly because the pupil does not change quick enough, that strong light is so painful, when we suddenly go into it, and that darkness seems greater at first than after we have been in it for a time. The pupil is not circular in the eyes of all animals, but is elongated vertically in beasts and birds of prey, and horizontally in those that graze.

505. The image on the retina is a *real*, not an *apparent* image, and is therefore *inverted.* It should occasion no surprise that we see objects *erect*, while the images are inverted; for the image is not the thing *seen*, but *that by means of which* we see; and we naturally judge that part of a body to be *highest*, which requires us to turn the eyes *upward* to see it directly.

Why would not our eyes serve for seeing in water? Is the pupil always of the same size? Why does it alter? Is the change voluntary? Explain the effects of going suddenly into strong light, or into the dark. Speak of the pupils in the eyes of animals. What is the position of the image? Why do we see things *erect?*

506. An object appears as *one*, though we see it by means of *two* images; but this is only one of many instances in which we have learned by experience to refer two or more sensations to one thing as the cause. Provided the images fall on parts of the retina which in our ordinary vision *correspond* with each other, then by experience we refer both impressions to one object; but if we press one eye aside, the image falls in a new place, and the object appears double.

507. The spot where the nerve enters the eye is insensible, and we cannot see any small object with either eye, when the image falls on that spot. This fact is not readily discovered, because an object can never disappear in this way to both eyes at once. To prove the fact it is only necessary to shut the right eye, and then turn the *left* eye about 15° to the *right* of any small conspicuous object, and it vanishes, though on turning the eye still farther away it reappears. Or the left eye may be shut, and the *right* eye turned to the *left* of the object.

508. *Long-sightedness.*—In early life the eye generally has power to converge the rays from an object until it comes within about *five* inches of it. Hence, this distance is often called *the limit of distinct vision,* since there is indistinctness if the object is nearer than this limit. But advancing age usually produces the effect of diminishing the convexity of the humors, and placing the limit of distinct vision farther off; and not unfrequently the limit is removed to an *infinite* distance, when no rays but those which are *parallel*, and perhaps not even those, can be converged to a focus on the retina. This defect of vision is termed *long-sightedness.* It can be remedied

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Why do we see an object *single?* What part of the retina is insensible? How may it be perceived? What is the *limit* of distinct vision? How great? The effect of age? Why? What remedy?

by the use of convex spectacles, which compensate for the too great flatness of the eye. As the eye does not sufficiently converge the rays of the several pencils, they fall on the retina in small *circles* instead of *points*, and these circles overlap and confuse the details of the image. A lens of proper convexity causes the rays to converge more, and meet on the retina.

509. *Short-sightedness.*—When the eye has undue convexity then the limit is less than *five* inches; and when it is much less, there is likely to be another limit, *beyond* which all objects are indistinct. This is *short-sightedness.* The rays from objects beyond the greater limit are so much converged by the eye, that they meet in focal points before reaching the retina, cross at those points and fall in circles, which overlap, and cause confusion of the same kind as occurs in long-sightedness. The remedy for this is the use of *concave* spectacles, which, if they have the proper degree of curvature, just compensate for the excess of convexity in the eye.

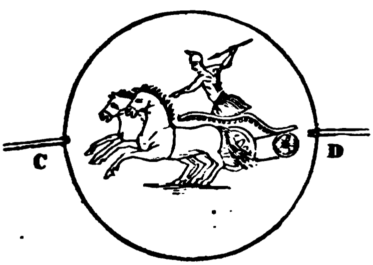
510. *Direct and indirect vision.*—To obtain a distinct and satisfactory view of an object, the axes of the eyes are ordinarily turned directly upon it, in which case each image is at the center of the retina. But when the light from an object is exceedingly faint, it is better seen by *indirect* vision; that is, by looking to a point a little on one side, and especially by changing the direction of the eyes from moment to moment on all sides of the object to be seen. Many of the fainter heavenly bodies are seen by indirect vision, when by direct vision they cannot be distinguished at all.

511. *Continuance of impressions.*—The impression which

Why is the image indistinct? What is *short-sightedness?* What *other* limit in this case? Why is there indistinctness? How cured? What is *direct* vision? *Indirect* vision? When is the latter useful? Describe cases.

a visible object makes upon the retina, ordinarily continues about one-eighth or one-ninth of a second; so that if the object is removed for that length of time, and then reoccupies its place, the sight of it is not interrupted. A red-hot end of a brand, if whirled eight or nine times in a second, appears in all parts of the circumference at once. Two pictures on opposite sides of a disk are brought into view together, as parts of one and the same picture, by whirling the disk rapidly on one of its diameters. Such an instrument is called a *thaumatrope*. Fig. 184 represents the appearance produced when horses are painted on one side, and chariot and charioteer on the other. The *phantasmascope* is constructed on the same principle. Several pictures are painted in the sectors of a circular disk, representing the same object in a series of positions. These are viewed in a mirror, through holes in the edge of the disk, as it revolves quickly in its own plane. Each glimpse which is caught, whenever a hole comes before the eye, presents the object in a new attitude; and all these views are in such rapid succession, that they appear like one object going through the series of movements.

Fig. 184.



512. There are impressions on the retina of another kind, which are produced by strong lights; they continue for a

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How long do visual impressions last? Illustrate by experiment. Describe the *thaumatrope*. The *phantasmascope*. Explain each. What other kind of impressions, and in what circumstances?

longer time, and are in respect to color unlike the objects which produce them. They are commonly called *accidental colors*. If a particular part of the retina is for some time affected by the image of a bright-colored object, and then the eyes are shut, or turned upon a white surface, the *form* appears to remain, but the *color* is complementary to that of the object; and its continuance is for a few seconds or several minutes, according to the vividness of the impression. Hence it is, that patches of sky nearly white appear *green*, when the eye is strongly affected by *red* clouds.

513. *Estimate of distance and size of bodies :—*

1. If objects are near, we judge of relative distance by the *inclination of the optic axes* to each other. The greater that inclination is, or, which is the same thing, the greater the change of direction in an object, viewed first by one eye, and then by the other, the nearer it is. If objects are *very* near, we judge of their distance by the divergence of the rays which enter one eye alone.

2. If objects are known, we estimate their distance by the *visual angle* which they fill, having by experience learned to associate together their distance and their *apparent*, that is, their *angular* size. The smaller any known object appears, the farther off do we judge it to be.

3. Our judgment of the distance of remote objects is influenced by their *clearness* or *obscurity*. Mountains, and other features of a landscape, if seen for the first time when the air is remarkably pure, are estimated by us nearer than they really are; and the reverse, if the air is unusually hazy.

What are they called? How do they differ from the objects? What does their continuance depend on? Example of sky and clouds. State the first method of judging of distance. If objects are *known*, how do we judge? What effect has the state of the air?

4. Our estimate of distance is more correct, when *many objects intervene.* Hence it is, that we are able to place that part of the sky which is near the horizon, further from us than that which is over our heads. The apparent sky is not a hemisphere, but half of an oblate spheroid.

514. Our judgments of distance and of magnitude are closely associated. If objects are known, we estimate their distance by their apparent size, as has been stated; but if unknown, we must first judge of their distance by some other means, and then we are prepared to estimate their real, from their apparent size. And if we mistake as to the distance, we inevitably mistake also in respect to size. An insect crawling slowly on the window, if by mistake it is supposed to be some rods beyond the window, will appear like a bird flying in the air, or like a beast bounding over the earth. The moon near the horizon appears larger than above us, because by means of the intervening objects we are able to locate it further off.

515. *Binocular vision.*—If an object is quite near us, we have two different views of it at once,—one by the right eye, the other by the left. By the right, we see more of the right side; by the left, more of the left side. By these two views we learn to judge at once of the *relief* of an object, that is, the different distances of its parts from us. In this respect, *binocular* vision, or vision with *two eyes*, has a great advantage over vision with one eye.

516. *The stereoscope.*—Pictures may be made to appear in relief, like real objects, if the view presented to one eye differs

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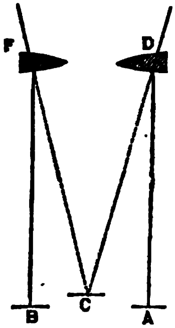
The *fourth* way. What is the apparent shape of the sky? Show how error in judging of distance affects our judgment of size. Examples. Insect. Moon. What is binocular vision? What advantage has it over vision with *one* eye? Describe how *pictures* may produce the same effects as real objects.

from that presented to the other, just as the two views of the real objects would differ. This is accomplished by taking two photographs of an object from different points of view, and so placing them, that each is seen only by one eye, and yet both appear to occupy the same place. An instrument which enables us in this way to view a pair of pictures as one real object, is called a *stereoscope.* Let the photograph, which was taken from the right-hand point of view, be placed at A (Fig. 185), the other at B. Two halves of a convex lens, D and F, are placed above, with their thin edges towards each other. The pencils of light from A and B pass through D and F, and are bent outward, so as to appear to come from one picture at C. The lenses also produce a magnifying effect. In this way, an appearance of *relief* and *reality* is given to surface pictures, precisely like that obtained from viewing the objects themselves.

Fig. 185.



What instrument enables us to do this? Are the two parts of a sterograph alike? How should they differ? How are the lenses placed?